OLUME 53 NUMBER 12 . . . ONE YEAR FOUR DOLLARS

GENERAL ELECTRIC Review

TABLE OF CONTENTS
Page Three

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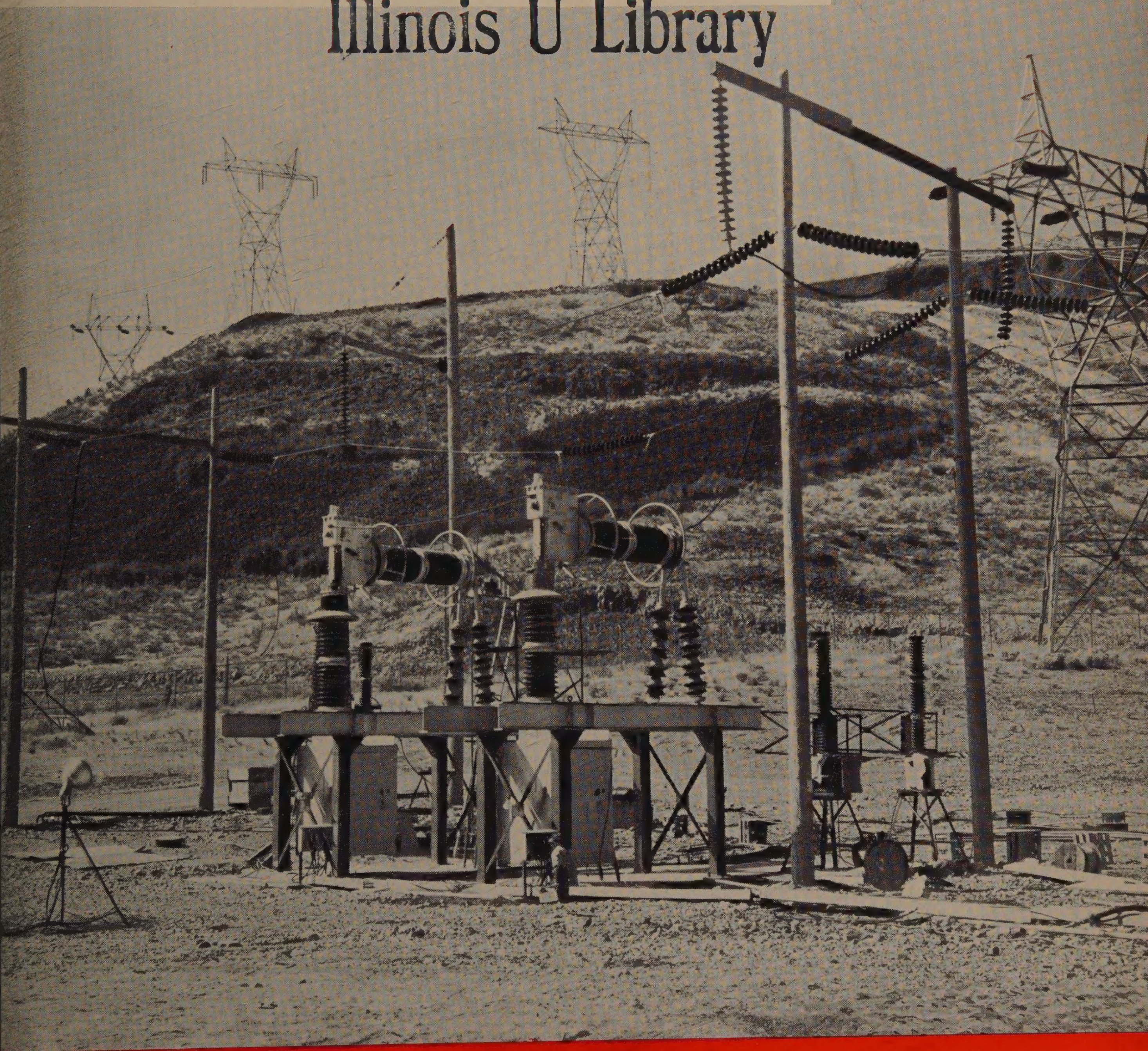

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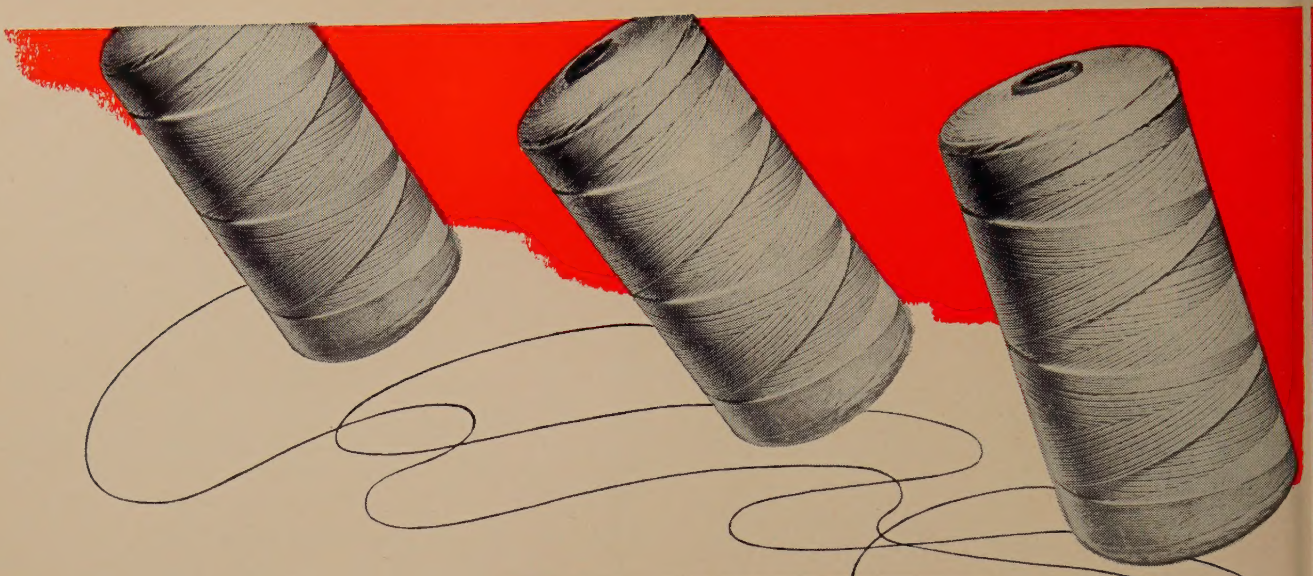

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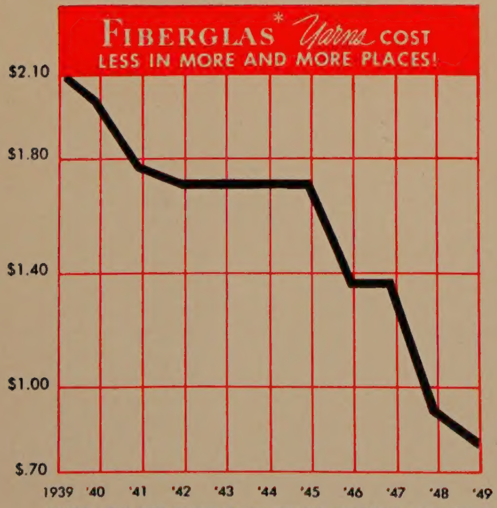

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GENERAL ELECTRIC Review

DECEMBER 1950
Vol. 53, No. 12

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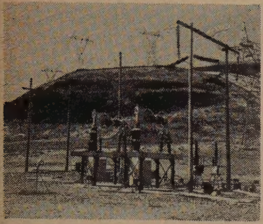

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Recent record-breaking field test of a 230-kv circuit breaker of the well-known low-oil-content type. In this test the breaker demonstrated its huge interrupting capacity by easily interrupting 12,000,000 kva, which is the maximum fault capacity available at Grand Coulee at present. This year is noteworthy not only for field tests but also for greatly expanded laboratory facilities for scientific research and engineering investigation. Some of them and many of the year's product developments in electrical fields will be described in our next issue.

ADVERTISING INDEX

Air-Maze Corp. 52
American Brass Co. 21
American Lava Corp. 55
Ampex Electric Corp. 53
Anaconda Copper Mining Co. 21
Armco Steel Corp. 4

British Thomson-Houston Co., Ltd. 38

Canadian General Electric Co., Ltd. 33
Clarostat Manufacturing Co., Inc. 38
Combustion Engineering—Superheater, Inc. 20
Cornell-Dubilier Electric Corp. 5

Distillation Products, Inc. 6
Driver-Harris Co. . . . . 4th cover

Edison-Swan Electric Co., Ltd. 38

Ferguson Pailin Ltd. 38

General Electric Co. 1, 7, 24, 34, 46, 56, 60
Giannini and Co., G.M. 51

Hotpoint Electric Appliance Co., Ltd. 38

Ilsco Copper Tube & Products, Inc. 46
Ingersoll-Rand Co. 39

JFD Manufacturing Co., Inc. 53
Johns-Manville Inc. 19

Mallory and Co., Inc., P.R. 35
Marion Electrical Instrument Co. . . . . 3d cover
Metropolitan-Vickers Electrical Co., Ltd. 38
Metropolitan-Vickers-GRS, Ltd. 38
Miniature Precision Bearings, Inc. 33

New Departure—Div. General Motors Corp. 2
Newton Victor, Ltd. 38

Owens-Corning Fiberglas Corp. . . . . 2d cover

Penn-Union Electric Corp. 58

Rider Publisher, Inc., John F. 54

Sexton Can Co., Inc. 24
SKF Industries, Inc. 25

Tempil Corp. 59

West Virginia Pulp & Paper Co. 24

EDITORIAL CONTENTS

FRONTISPIECE: Futuristic? . . Probably Not for Long . . . 8

EDITORIAL: Power Systems Engineering . . . S. B. Crary 9

ARTICLES:

Year-round Air Conditioning with the Heat Pump . . . F. R. Ellenberger 10

Notable progress already made in industrial and residential installations of the heat pump. How it economically and technically fits into year-round air-conditioning requirements

Magnification of Switching Overvoltages in Coupled Oscillatory Circuits . . . . . I. B. Johnson and John Berdy 22

Unusual field experiences, analyzed and verified with transient analyzer, aid in making effective designs and applications

Reactors in Low-voltage Industrial Power Systems of 600 Volts or Less . . . . . D. L. Beeman and L. L. Baird 26

The application of a new compact type of current-limiting reactor unit now becomes a convenient means of obtaining short-circuit protection in certain types of installations

High-voltage Load-ratio-control Contactors . J. F. McKenney 36

How the basic structures of this switching equipment permit handling of high voltages. Example of size and weight reduction resulting from fundamental changes in contactor design

Spotting Equipment for Synchronous Motors . . . S. C. Ewing and E. A. E. Rich 40

Accurate angular positioning of heavy rotors accomplished by simple control that gives slow rotation in either direction

A New Type of Controlled Wave Shape Generator . . . W. D. Williams and R. D. Robinson 47

New electronic power supply for producing desired wave shapes of voltage, to provide data on electrical and magnetic phenomena associated with nonsinusoidal excitations

DEPARTMENTS:

High Lights and Side Lights . 51
New Products 52
Trade Literature . . 53
Book Reviews . . 54
Library Notes . . 59

INDEXED: By the Industrial Arts Index; the Engineering Index; and Science Abstracts

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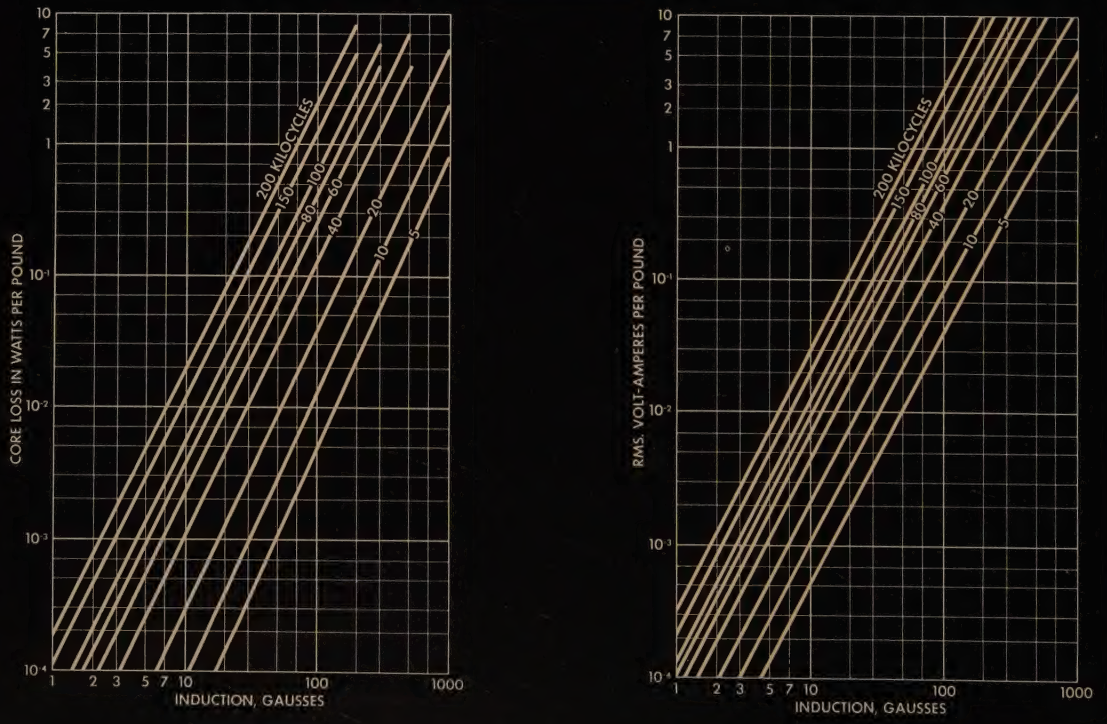

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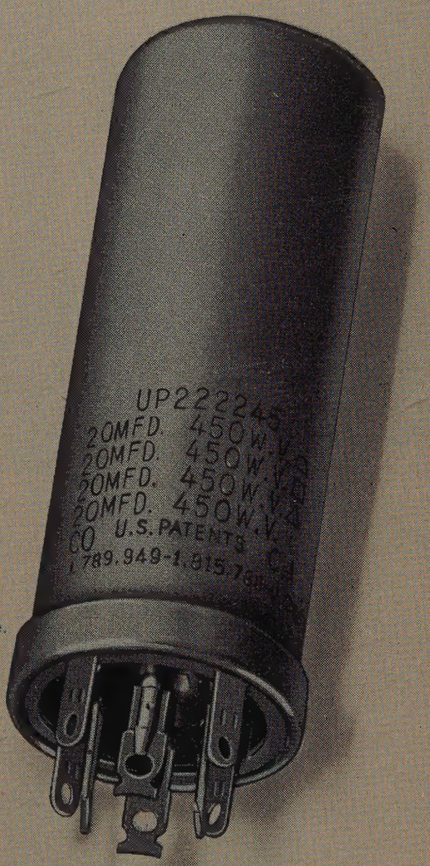

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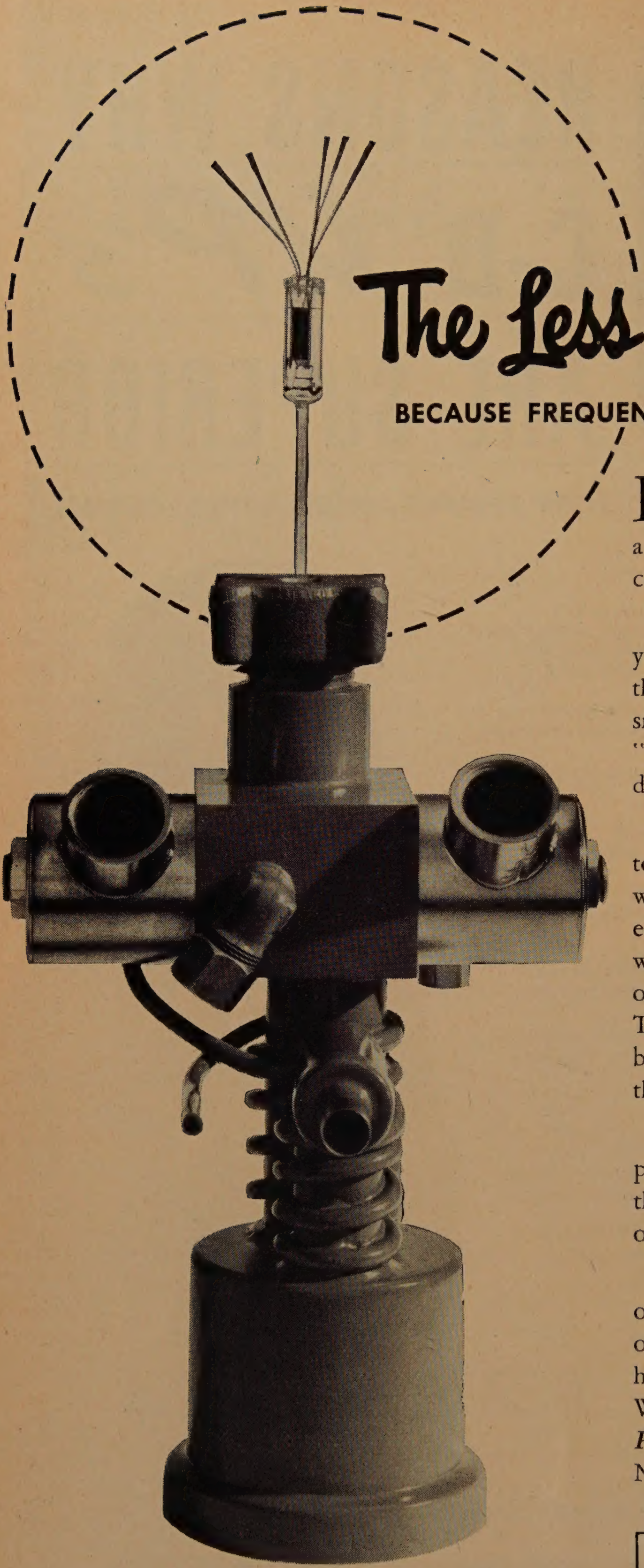

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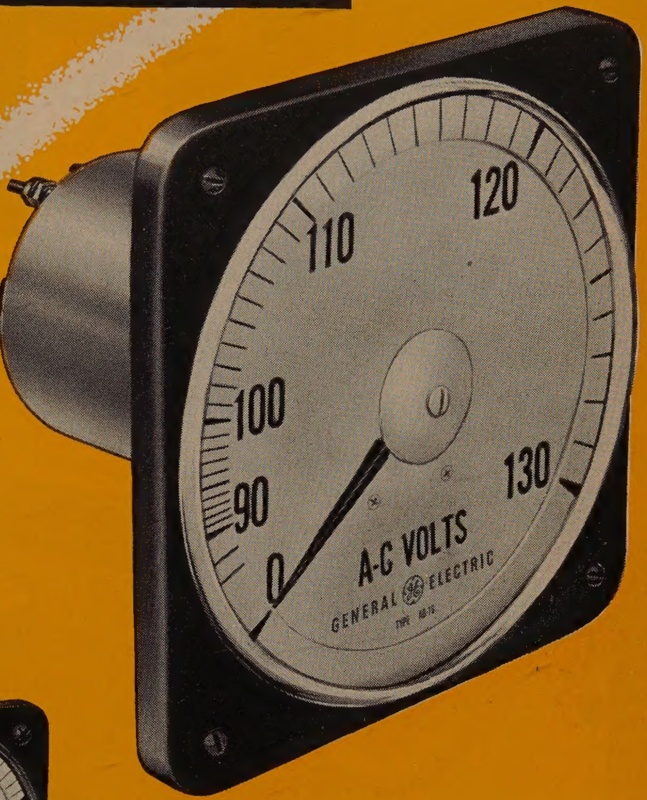

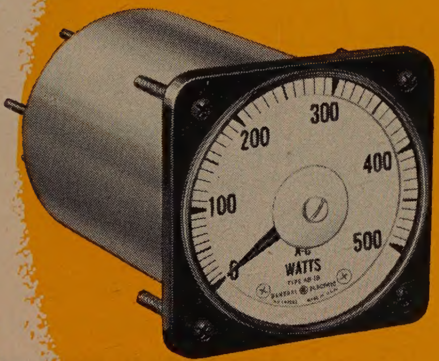

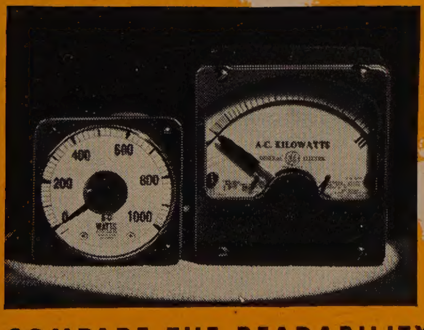

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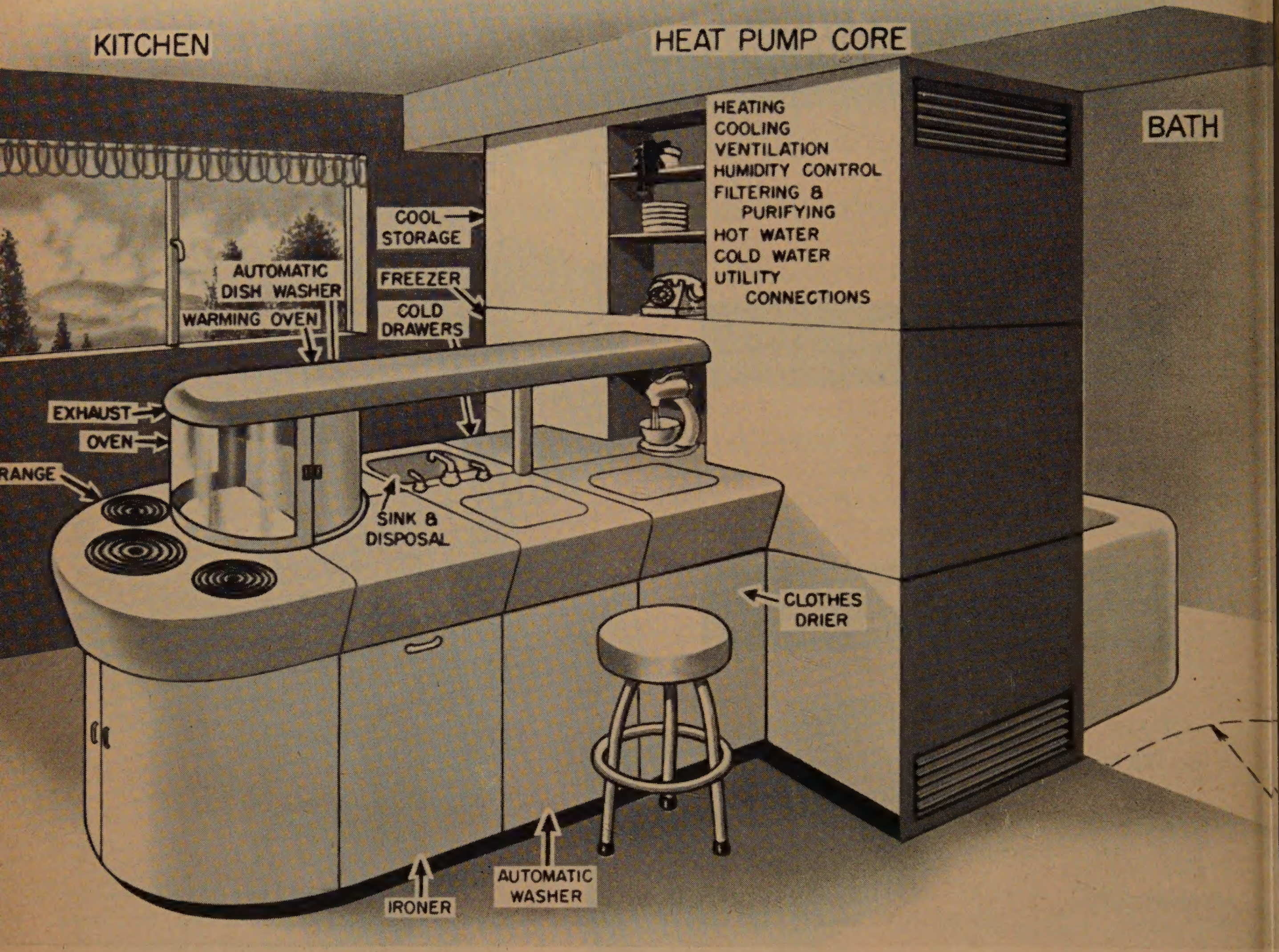

FUTURISTIC? . . . . . PROBABLY NOT FOR LONG

One man's conception of what might be the appearance of the kitchen in a home that is made an all-electric dream house by the inclusion of a package heat pump to economically co-ordinate all the home's thermal requirements. In his article on page 10, Mr. Ellenberger describes the rapid progress now being made in the development and application of heat pumps for year-round air conditioning of homes and commercial buildings

GENERAL ELECTRIC Review

Vol. 53 DECEMBER 1950 No. 12

POWER SYSTEMS ENGINEERING

THE demand for electrical energy grows apace. Records show a growth in all areas and countries, doubling about every 6 to 12 years. This requirement for electricity necessitates the *immediate* solution of many new and difficult problems. In financing the new investment and in manufacturing the equipment there are problems that require courage and skill. Some of the other important problems in maintaining this healthy growth and vitality fall upon the systems engineer.

As the system grows in concentration and extent the engineer must plan to make full use of the advantages of such growth, lest the disadvantages of size overtake him. He must resort to new tools and develop new skills to assure that the growth will be used most efficiently to attain a better system. All the drives of the American enterprise system are in the direction to encourage and reward engineering efforts to reduce the cost of a reliable supply of electrical energy. This is a challenging job and one which the utilities are tackling with renewed co-operation and enthusiasm. It is a task which requires group co-operation and a continual self-searching for improvement.

Philip Sporn in his recent book *The Integrated Power System* presents a most concise and stimulating picture of the modern power system with emphasis on the tools and co-ordination required to obtain efficient performance. The last two sentences in his book quite properly sum up the efficient performance of an integrated power system. After making a comparison with national averages of fuel station efficiencies and system losses, he states:

> "The combined savings, as the result of higher efficiency of steam plants and lower system losses, will be 2,650,000 tons of coal per year.
>
> "This is not only a very substantial figure, whether considered from the economic angle or from the conservation-of-resources viewpoint, but of equal significance, the savings automatically increase as growth takes place, provided, of course, the basic concepts of a sound integrated system are not infringed upon."

One of the fundamental and more pressing necessities for intelligent growth requires new recruits, well trained and of good quality. It is the younger engineers who can most readily acquire and apply new tools and methods, with the older and more experienced men to guide them.

Much attention has been given recently to training system engineers and considerable progress has been made. The utilities have supplemented their own training programs with co-operative training with the manufacturers, both for the college graduates and for their more experienced up-and-coming engineers. For example, thirteen utility engineers are enrolled in the General Electric Power Systems Engineering Course, taking the same courses which were developed as on-the-job training for the manufacturer's application engineers in Schenectady.

Another logical step in this program to attract high-grade engineers to the power industry is to bring the attention of the engineering students and their professors to the challenging and important problems which the utilities have before them—of the new problems which size and rapid growth have placed on the system engineer. Problems of load and frequency control, of load dispatching for maximum system economy, and the development of steps for the best procedures to follow under emergency system conditions. All these problems require a fundamental understanding of performance under normal and abnormal conditions. This ability to contribute to the efficiency and performance of a large system requires a thorough knowledge of the characteristics and performance of the individual elements of the system. This background requires intensive training and experience so that practical and worthwhile results may be obtained. There is no short cut to attaining this goal. Power-systems training and recruiting programs must be supported and sustained to meet the competition of other attractive opportunities for the engineering graduates.

We should make sure that the new generation of young engineers appreciates these opportunities so that the electric power industry will continue to obtain the high-quality personnel it requires.

S. B. CRARY

YEAR-ROUND AIR CONDITIONING WITH THE HEAT PUMP

FR Ellenberger

Notable progress already made in industrial and residential installations of the heat pump. How it economically and technically fits into the year-round air-conditioning requirements, providing utility in that service over wide areas

By F. R. ELLENBERGER
Air Conditioning Department, General Electric Company

THE trend toward complete year-round air conditioning of residences as well as larger buildings has focused increased attention on the heat pump. Since 1932, when the residential heat pump was first being investigated in this country,(1)(2) 750 heat pumps have been installed in the United States; 60 percent of the installations are in residences and 40 percent are commercial. Heat pumps are currently being installed at the rate of approximately ten per week. FIG. 1 shows an office building that is completely air conditioned, summer and winter, by a custom-designed heat pump. FIGS. 2 and 3 illustrate package, or self-contained, heat pumps that are completely assembled in the factory for installation in residences and other small buildings.

The functions of year-round air conditioning provided by heat pumps include heating in winter, cooling and drying in summer, air filtering, circulation, and ventilation. These functions are accomplished electrically, under automatic control, without combustion, and without fuel in the ordinary sense.

The basic principle is the same as is used in a common electrically operated refrigerator. A simple illustration of its operation can be obtained by imagining that a refrigerator with its door removed is placed against an open window. Then heat removed from the outdoor air by the refrigerator evaporator is dissipated from the condenser into the house. For cooling, the refrigerator could be placed outside the house against the same open window. Then heat removed by the evaporator would be pumped outdoors. Of course, the domestic refrigerator is not designed for this application; its capacity would be much too small; and its operating economy for this type of operation would be low.

Fig. 1. Office building with year-round air conditioning provided by custom-installed heat pump

HOW HEAT IS PUMPED

Although the operating principles of heat pumps have been widely described,(3)(4) it seems in order to risk repetition by reviewing their relatively simple fundamentals.

FIG. 4(a) illustrates the phenomenon of heat absorption by a boiling liquid. Heat applied to the liquid in the flask is used to raise its temperature to the boiling point and change it to a vapor. When this vapor is cooled below its vaporizing temperature, it will give off its latent heat of vaporization and condense back to liquid form. At atmospheric pressure, the boiling in the flask and the condensing in the condenser tubing will occur at 212 F, and all the heat absorbed from the flame by the water will be transported and released in the condenser. At pressures less than atmospheric, the water will boil at temperatures less than 212 F. If a vacuum pump is attached to the flask, as in FIG. 4(b), and the pressure in the flask (evaporator) is reduced to 0.36 lb per sq in., the water will then boil in an ambient temperature of 70 F. Since the vacuum pump exhausts the vapor to atmospheric pressure of 14.7 lb per sq in., the vapor will condense back to a liquid at 212 F. Thus, by virtue of the work required to pump the vapor from the lower to the higher pressure, heat is absorbed at the temperature of 70 F and released at 212 F.

Substances with more suitable characteristics than water are available for this purpose and are known as refrigerants. Among their more desirable properties is the ability to evaporate at low temperatures with satura-

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(1) Numbered references are listed at the end of this article.

This article is so paged that, without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—EDITOR

Fig. 2. Three-horsepower package heat pump for residential air conditioning

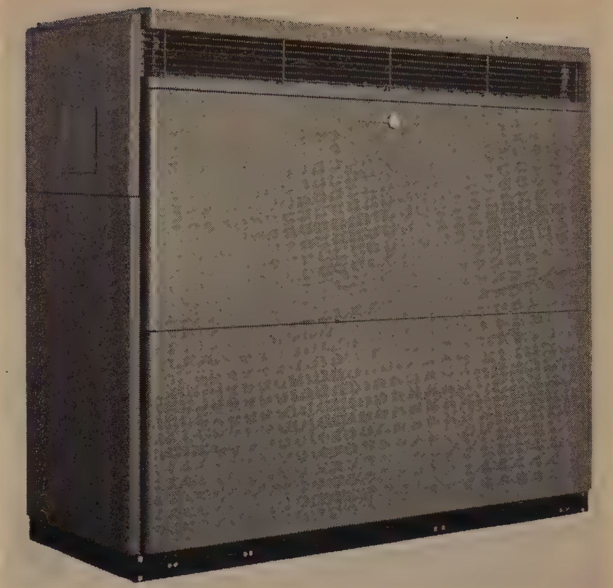

Fig. 3. Six-horsepower package heat pump for the larger residences and small commercial buildings

tion pressures greater than atmospheric, with the consequence that high vacua are not required. If Freon 12, one of the most commonly used refrigerants, is employed in the apparatus shown in FIG. 4(b), heat can be absorbed at a temperature of 32 F and given off at 100 F with a pressure of 72.5 lb per sq in. in the evaporator and 212.6 lb per sq in. in the condenser.

To permit the reuse of the refrigerant, the condensed liquid can be returned to the evaporator through a pressure-reducing orifice, or expansion valve, thus completely sealing off the refrigerant system from the atmosphere. There results the complete refrigerating system, as in FIG. 4(c), capable of continuously extracting external heat at one temperature and delivering it to a higher temperature. For use as a refrigerator, the evaporator is placed inside an insulated container, and heat is pumped to the outside. For a heat pump that can be used alternatively as a heater or a cooler, it is not necessary to reverse the cycle, as is commonly supposed, but simply to utilize the heating effect of the condenser or the cooling effect of the evaporator as is desired.

Basic thermodynamics teaches that a refrigerating system, or heat pump, is actually the reverse of a heat engine. The latter transforms heat energy from a heat source at a high temperature level into mechanical work and into heat rejected to a lower temperature sink. Whereas the energy relation for a heat engine can be expressed as:

Heat absorbed at high temp. *equals* Work produced *plus* Heat rejected at low temp.

and the efficiency as:

Work produced *divided by* Heat absorbed at high temp.
(The ratio being always less than one)

the equivalent energy relation for a heat pump is:

Heat given off at high temp. *equals* Heat absorbed at low temp. *plus* Work required.

For the present purpose, efficiency in the ordinary sense has little meaning; but a measure of heat-pump performance is the ratio of heating (or cooling) energy divided by the thermal equivalent of the work input. This is known as Coefficient of Performance. The arrows in FIG. 4(c) designate the energy quantities of a refrigerating (heat-pump) system. If, under certain

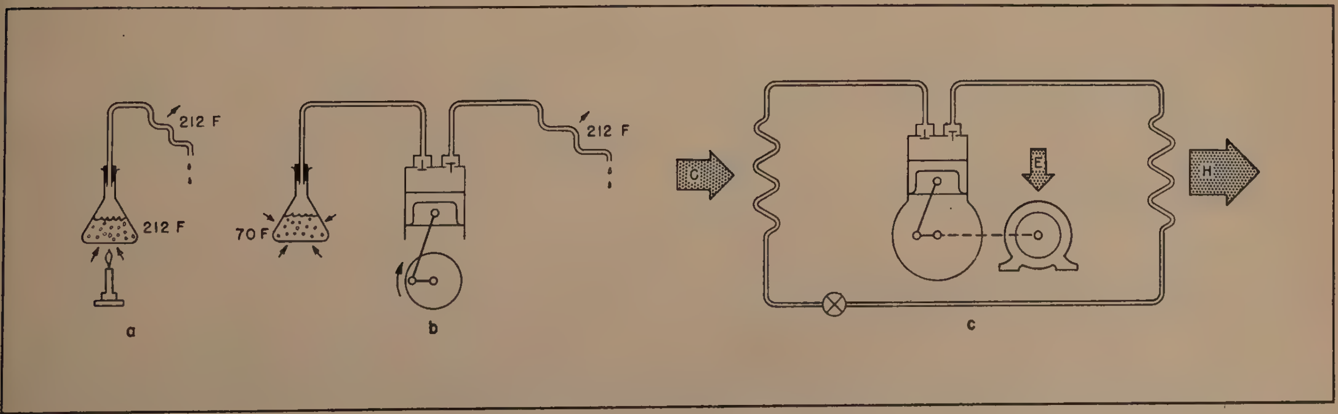

Fig. 4. Fundamentals of heat-pump operation

conditions, two units of heat energy C are absorbed in the evaporator for every unit of electrical energy E (in equivalent energy units), the coefficient of performance for cooling will be C/E or 2. At the same temperature conditions, H, the heat given off from the condenser will be equal to C plus E, and the coefficient of performance for heating will be 3. As a heater, under these conditions, the heat pump will furnish useful heat with one-third the electrical energy required to produce the same amount of heat were the electrical energy all consumed in resistance heaters.

Contrary to some popular notion, this does not mean getting free heat. It simply means the utilization of high-grade electrical energy to raise the temperature level of heat existing in the environment while lowering the temperature level of the electrical energy.

It is basically a tremendous waste to consume high-grade energy to maintain the temperatures of our houses at about 70 F in winter, because all the heat generated is ultimately dissipated to the atmosphere. Currently, it is estimated that about 9000 trillion (9×10^{15}) Btu of heat energy are so dissipated each winter in the United States. As an example, consider somewhere in the central part of this country a small house that may require 100 million Btu of heat each winter. It may require burning seven tons of coal in a furnace to produce 200 million Btu of heat. This produces a temperature of approximately 2000 F which must be reduced to a much lower value for comfort heating purposes, and which requires the introduction of about 140 tons of cold air into the house to support combustion. One-half of the heat may go directly up the chimney, while the remainder heats the interior of the house before leaking out through the walls, windows, doors, and roof to heat the atmosphere. Contrast this circumstance with that of a tight, well-insulated house having a heat pump which recovers from the atmosphere a major portion of all the heat that escapes through the walls, and pumps it back to the inside of the house, and continues to do so.

A modern central power station can deliver, to the user, electrical energy equal to 30 percent of the original energy in the fuel consumed. A heat pump having an average performance coefficient of 3 can then make heat available at a rate equal to 90 percent of the total fuel energy. Combustion in the central power station thereby provides an increase in coal utilization from 50 to 90 percent. A heat pump having a coefficient of 4 can make possible a substantial saving of fuel resources since it can produce heat energy equivalent to 120 percent of the fuel energy.

To facilitate the selection of either the heating or the cooling effect of a heat-pump system, it is necessary to interchange either the heating and the cooling media in contact with the evaporator and condenser, or the functions of the evaporator and condenser heat-transfer surfaces. One common method for accomplishing the latter is illustrated in Fig, 5. wherein valves *2* and *3* are opened and *1* and *4* are closed for heating. High-pressure hot refrigerant gas from the compressor passes through valve *2* to the indoor coil where it condenses to liquid and drains through a check valve into the receiver, still at high pressure. From the receiver it is forced through an expansion valve into the outdoor coil where it evaporates at low temperature and pressure. Vapor formed by the refrigerant boiling in the outdoor coil passes through valve *3* and is drawn into the compressor to start again its journey. For cooling operation, valves *1* and *4* are opened and valves *2* and *3* are closed. The indoor coil now becomes the evaporator and the outdoor coil the condenser.

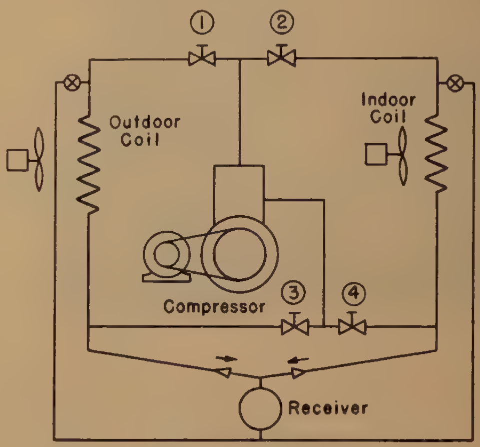

Fig. 5. Typical heat-pump refrigerant circuit

HEAT-PUMP APPLICATIONS

Since a heat pump provides means for extracting heat from one medium and delivering it to another at higher temperature, it is possible to visualize numerous applications of this principle. There is a large field of industrial processes in which such heat manipulation is desirable. For example, in the concentration of liquids the heat-pump principle has been applied in such a way that the evaporated vapor is compressed to a higher temperature and pressure and then condensed in a heat exchanger which delivers heat to the solution and keeps the process going. It is thus necessary only to supply heat to overcome the thermal head and to make up the losses, since the latent heat used for boiling off the distillate is recovered. Another example is in process drying, where a warm atmosphere is produced by a refrigeration condenser and, after absorbing moisture from the material being dried, is passed over the evaporator of the refrigeration system where the evaporated moisture condenses to water. Here again, the heat required to evaporate water is recovered, and the necessary energy input is smaller than that when heat from combustion is utilized for this purpose. In addition, high-temperature hazards are eliminated.

Such processes to date have been more popular in Switzerland where ordinary fuels are scarce and water power more plentiful.

In this country the industrial application of the heat-pump principle has recently received great impetus from the Florida citrus-fruit industry which has been applying this principle to concentrate and freeze orange juice.(5) A large portion of the heat required for evaporating water from the juice is recovered by the subsequent condensation of the vapor, as well as from the heat made available in freezing the concentrate.

In fact, wherever low-grade heat is normally dissipated, consideration can well be given to its recovery and transformation to higher temperatures by the use of a heat pump.

Another interesting application of the heat-pump principle is the heating of domestic water. Fig. 6 shows a developmental heat-pump water heater made by Hotpoint, Inc., a General Electric affiliate. In addition to the ordinary advantages of electric water heating, the heat-pump water heater consumes less electrical energy. An additional benefit is that the cooling effect of its evaporator can often be put to good use. It will serve, for example, to keep an otherwise damp basement dry.

Undoubtedly the largest potential for the application of heat pumps lies in year-round air conditioning. Mention has already been made of both custom-built and package units. Heat pumps for air-conditioning application offer the following advantages to the user:

(1). They provide healthful and comfortable air conditioning the year round. A single unit can automatically give heating, cooling and dehumidification, or ventilation as required. These can be provided without regard to outdoor conditions, and it is not necessary to manipulate windows and shades in an attempt to obtain comfort. In this connection, it can be noted that in most localities there are many days throughout the year when it is cool at night and in the morning, but warm in the afternoon. To achieve optimum comfort under such conditions, it is necessary to employ both heating and cooling operations in the same day. This the heat pump does with ease.

(2). The heat pump will make possible the complete all-electric home, and will permit the user to pay for his "fuel" as it is used.

(3). Combustion, fuel delivery, and fuel-storage problems are transferred from the home to the central power plant of the utility supplying the electricity.

(4). Year-round comfort conditions are provided without dirt, ashes, odors, or products of combustion. The heat pump is characterized by the safety and cleanliness of electrical equipment.

(5). Means do not have to be provided for disposing of hot exhaust gases during the heating season. If not desired for other reasons, the chimney may be omitted entirely.

It is true that many of these advantages can be obtained by other types of year-round air-conditioning systems; a combination oil- or gas-fired furnace with a mechanical cooling system is a typical example. For ultimate convenience, however, the heat pump is the only device that can provide all these advantages from a single all-function piece of equipment.

With the foregoing as a background, it should be worthwhile to examine the two major lines of endeavor which are being pursued to bring into being the widespread usage of heat pumps. These major considerations pertain to both economic development and technical development.(6)

ECONOMIC DEVELOPMENT

To properly evaluate the economic potential of heat pumps for year-round air conditioning, it is first necessary to establish basic market considerations. At the outset, it must be recognized that the heat pump is not, in general, a direct competitor to conventional automatic heating. Except for conditions such as extremely mild climate, high fuel cost as compared to that of electric power, or the existence of large quantities of cheap waste heat, there is little if any economic advantage at present to a heat pump for heating alone. Exceptions may also result because of novelty and pride of ownership, as well as the absence of combustion and other advantages cited in the previous section. However, when the heat pump is not considered as a heating machine, but as a machine for providing year-round air conditioning, its real economic usefulness begins to emerge.

Fig. 6. Heat pump for supplying domestic hot water

With this basic premise established, the economic potential of heat pumps will depend largely upon:

(1). *Climate:* Those portions of the country where summer cooling is necessary or desirable

(2). *Electric power:* Availability and relative cost as compared to that of other fuels

(3). *Consumer:* Habits and buying power

(4). *Economics:* National level of prosperity.

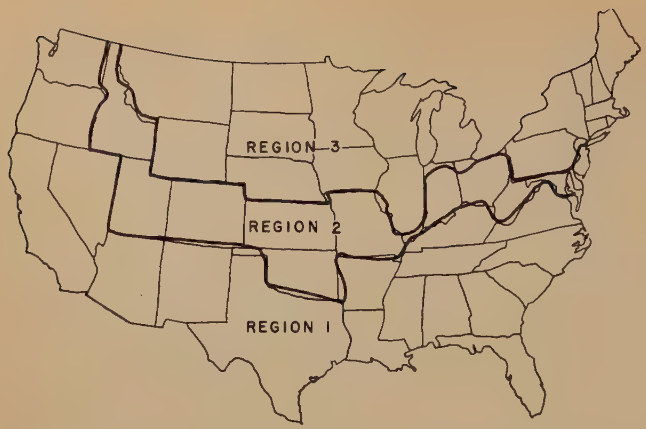

Fig. 7. Principal areas for application of heat pumps in the United States

These factors have been integrated in an approximate manner into a general picture in FIG. 7. The southern and west-coast regions of the United States, which are indicated as Region *1*, provide the best balance between heating and cooling. As time progresses it is expected that heating capacities will be increased and the demand for summer cooling will become more prevalent in the north. Peak summer temperatures are similar throughout the country, the essential difference being their greater frequency and longer duration in the south.

The first cost of providing summer cooling is at present about equal to the cost of an automatic heating system. Eventual quantity production of heat pumps should materially lower the first cost of year-round air conditioning to the extent that both heating and cooling will be available for a cost of perhaps only 50 percent greater than heating alone.

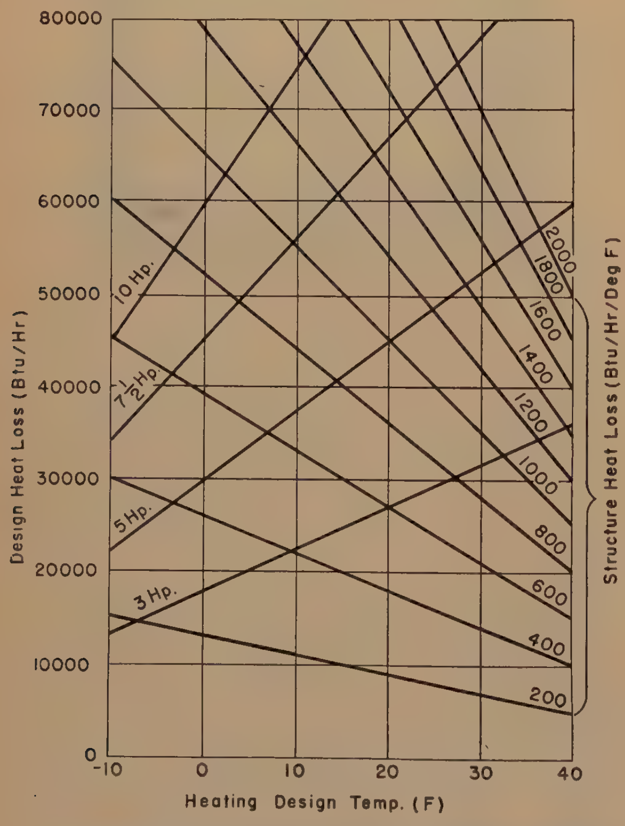

Fig. 8. Heat-pump sizes when determined by full heating requirements

A major consideration from the first-cost standpoint is the size of heat pump required which, in turn, is influenced by the climate.(7) Where the peak heating requirement is substantially greater than that required for cooling, it will be necessary either to install a unit larger than that required for cooling alone or to provide supplementary heating in cold weather. Usually, the total amount of supplementary heat required will be a small portion of the season's total.(8)

FIG. 8 illustrates the relation between the size of heat pump required for heating, the house size, and the design heating temperature. Representative data are used for heat-pump heating capacity,(3) and show, for example, that a building requiring 35,000 Btu per hr at a minimum outdoor temperature of 10 F would require a 5-hp heat pump to continuously supply the required amount of heat at the design temperature, without means for supplementary heating. A 10 F heating design temperature is typical for Birmingham (Alabama), Atlanta (Georgia), and Portland (Oregon). However, the temperature reaches 10 F on an average of less than once a year in those locations (once in 5 years in Portland). A daily mean temperature as low as 15 F is experienced on the average of less than once in three years.

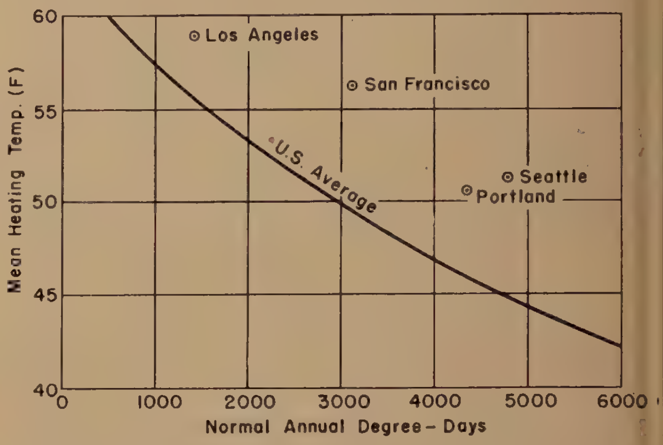

Fig. 9. Average winter temperatures during time heating is required

Taking into account transient heat flow (heat storage in structure which causes attenuation of outdoor temperature variation), as well as the effects of solar heating and indoor heat generation (from occupants, lamps, appliances), the standard design temperature appears somewhat conservative. On the basis of using the TAC* design temperature, the temperature which is exceeded for 97½ percent of the hours during December, January, and February, a design temperature of 22 F would be indicated for the localities mentioned. The heat loss of the building cited would be reduced to 27,400 Btu per hr at 22 F, and this requirement can be met by a 3-hp unit instead of a 5-hp unit.

A heat pump sized for a 22 F design heating temperature will generally be adequate in size to cool the same structure almost anywhere in the country. Generally, a heat pump is able to pump twice as much heat per degree temperature difference, between indoors and outdoors, on heating operation as on cooling. This is partly due to the fact, as was previously explained, that a refrigeration cycle has a greater coefficient of performance when heating than when cooling under the same conditions. Also, from 20 to 40 percent of its capacity when cooling is utilized in condensing moisture from the air, and a substantial portion of the cooling capacity is needed to counteract solar heat and internally generated heat. Consequently, the heat-pump application which has just been considered and which is sized to maintain a 48 F maximum indoor-outdoor temperature difference for heating, should be able to maintain a summer indoor temperature of 75 F when the outdoor temperature is as high as 99 F.

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* After Technical Advisory Committee of the American Society of Heating and Ventilating Engineers.

For commercial applications such as restaurants and stores, the high amounts of internal heat generated permit a smaller heating-cooling capacity ratio, making the heat pump particularly suitable for this application.(6)

The problem of operating cost is a matter of heat-pump coefficient of performance, size of structure, climate, and cost of electric power. The performance of the heat pump will be influenced largely by the average temperature of the heat source. FIG. 9 shows the average temperatures to be expected when the outdoor air is used as the primary heat source. The "mean heating temperature" is the average temperature existing for the hours that heating is required in a normal year. The number of annual degree-days (days times temperature below 65 F) is an indication of the severity of the climate. With the exception of localities on the west coast, which are noted separately, the mean heating temperature for any location in the country can be determined with close accuracy from FIG. 9. Birmingham (Ala), for example, which has 2611 normal annual degree-days, has a mean heating temperature of 52 F. Thus an air-source heat pump in Birmingham should have the same operating efficiency over a normal season as it would have if the temperature were constant at 52 F for the same number of hours of heating operation.

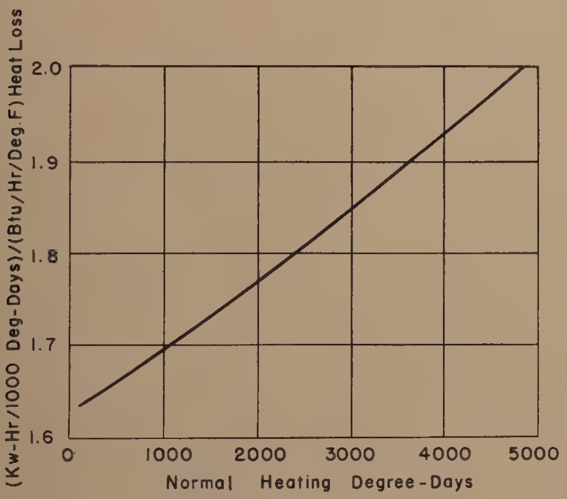

Fig. 10. Power consumption for heating

FIG. 10 incorporates the correlation of FIGS. 8 and 9 to yield the estimated annual power consumption. A house in Birmingham (Alabama) should require therefore 1.82 kw-hr per 1000 degree-days for each Btu per hr per deg F of heat loss. If the heat loss of a house is 35,000 Btu per hr at 10 F, its unit heat loss is 35,000/(65−10) or 636 Btu per hr per deg F, and for a normal season of 2611 degree-days, a total electrical consumption of 1.82×2.611×636=3190 kw-hr will be required for heating.

A comparison of operating cost for heat-pump heating as compared to oil heating can be obtained from FIG. 11. With electricity at 1½¢ per kw-hr, and with an average coefficient of performance of 3.0, the heat pump will compete with oil at 13¢ per gal.

Operating cost for cooling will approximate that for conventional cooling systems and will not be elaborated upon here. From 200 to 2000 hr of operation per year may be required depending upon location and type of application. The operating cost for both heating and cooling will be influenced to some extent by individual application, user habits, and microclimate (differences between local and regional climate). Costs can be lowered by better insulation and sealing of structures as well as by more efficient heat-pump design.

Numerous utility companies, research institutions, and equipment manufacturers are currently engaged in investigations to more closely evaluate heat-pump operating data. The author's company has 16 package units at various locations for this purpose.(8) Most of these units are being tested in co-operation with local

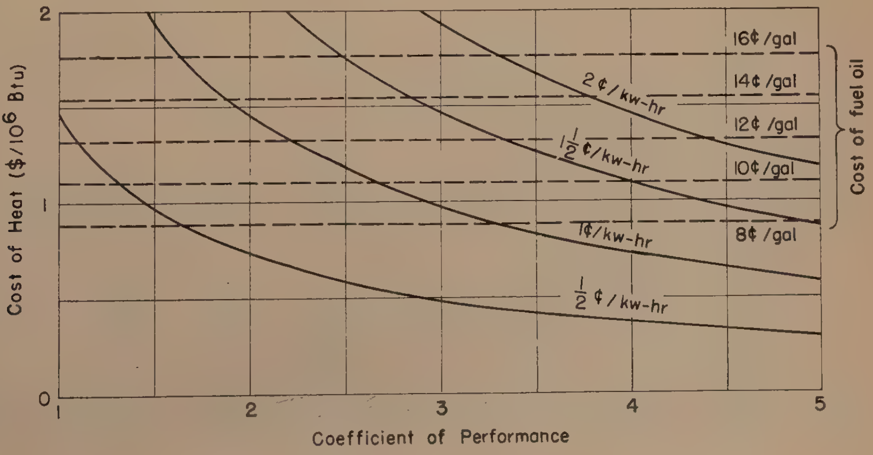

Fig. 11. Operating cost for heating compared to fuel oil

Fig. 12. New England house using package heat pump

electric utility companies. Fig. 12 shows a residence near Providence (R. I.) being used for this purpose in co-operation with the Narragansett Electric Company. Fig. 13 shows a medical clinic in Canton (Ohio) which contains a heat pump being evaluated jointly with the Ohio Power Company, a subsidiary of the American Gas and Electric Company.

TECHNICAL DEVELOPMENT

The basic operating principles of heat pumps having been described, more detailed consideration will now be given to the fields of heat transfer, refrigeration, and control.(6)(8)(9) Only the broader aspects of these problems will be outlined. The technical problems fall into two main categories: *external* conditions under which the heat pump must work, and *internal* conditions or manner in which the heat pump must satisfy the external requirements.

An important external condition is the heat source from which heat can be obtained in winter and to which it can be disposed in summer. Fig. 14 diagrams the three principal sources: well water, ground, and air.

Well water is an attractive heat source since its temperature in cold weather is considerably warmer than the air. It can be used as a heat source directly or indirectly. For the direct method, it is pumped from the well and heat is removed from it by reducing its temperature before it is discharged. To insure a sufficiently high evaporator temperature for efficient performance and to avoid the possibility of ice formation, it generally is necessary to pump at the rate of 3 to 4 gal per min for each horsepower of compressor size. This quantity may severely strain the capacity of the water strata, and, in addition may present a problem of disposal. If the well is deep, considerable pumping power is required. For that condition, it is possible to conserve pumping power by circulating a secondary fluid, as shown by the bottom diagram in Fig. 14(a). This method imposes the penalty of an additional temperature drop for heat transfer, and will work only if there is sufficient movement of underground water past the well; otherwise, continued removal of heat may reduce the temperature of the water in the well casing until it freezes.

Another method that is receiving much attention is that of providing heat for the heat pump by burying a heat exchanger directly in the ground. Many research projects have been undertaken to investigate this problem and they have shown that the earth's suitability as a heat source varies widely with the type of soil and with the amount of moisture present. One common misconception is that heat so obtained comes from the center of the earth. Actually, an insignificant amount comes from that source: the real source is either moving underground water or the storage of heat from the sun and atmosphere. Essentially, the ground is an insulator. This explains the fact that its temperature below depths of about 25 ft remains nearly constant throughout the year. When heat is withdrawn, however, its temperature may be considerably reduced before the steady-state condition is reached where heat is replaced at the same rate as that taken.

Fig. 13. Medical clinic conditioned in all seasons by package heat pump

As illustrated in Fig. 14(b), an evaporator coil may be imbedded directly in the ground or an indirect system may be used wherein water or an antifreeze solution is circulated through the buried ground coil.

The remaining common source of heat for the heat pump is the atmosphere. This source appears in most instances desirable from an economic standpoint. Its particular advantage is that it is universally available, and, unlike many other sources, its characteristics are generally predictable. Its obvious disadvantage, of course, is that it is coldest at about the time the most heat is needed. As indicated in Fig. 14(c), either outdoor air may be passed over the heat-pump evaporator and its temperature reduced to obtain heat, or, in cases where large quantities of air are being expelled for ventilation or other purposes, it is feasible to extract all, or a large portion, of the required heat from it.

Other sources of heat are sometimes available. Streams or open bodies of water under some conditions have been found practicable, and municipal water has been particularly useful as a supplementary source to outdoor air during periods of low temperature. Some attention is also being given to the possibilities of heat stored by a solar radiation collector.

Another major external condition to be considered is the climate. Mention has already been made of the importance of establishing a heating-design temperature just low enough to insure sufficient heating capacity, and yet not so low as to require an oversized unit. For conventional heating equipment, some extra capacity is relatively easy to obtain by an increase in fuel consumption, and generous safety factors are usually employed in sizing. Extra capacity in a heat pump requires that the major components be substantially larger, and an increased peak power demand is imposed. Consequently, more exact methods must be used for properly sizing heat pumps to the climate and structure. Current studies are being made of this problem.

It is quite probable that the advent of the heat pump and a more detailed awareness of the effects of climate will greatly influence future residential design. Windows will be designed only to see through—and not as transparent openings with contrivances added in an attempt to reduce infiltration of air, dirt and insects. There will be little need for screened porches and bulky chimneys. Houses will be more correctly oriented to reduce the effect of winter wind and to obtain the maximum benefit from solar radiation in winter and its exclusion in hot weather. They will be better insulated, and air leaks will be reduced to the minimum. The required amount of ventilating air will be brought in and cleaned and conditioned under automatic control.

A picture of the quantitative performance characteristics of a heat pump can be obtained by reference to Fig. 15. The effect of heat-source temperature upon heating capacity and power requirement is evident. Also shown is the average heating requirements of a typical building. When outdoor air is used as a heat source, the two characteristics can be superposed to illustrate the low-temperature characteristics of the air-source heat pump when utilizing a fixed-displacement constant-speed compressor. The compressor power drops off at low outdoor temperatures. This results from the fact that, as the evaporator temperature drops, the saturation pressure of the refrigerant rapidly decreases, and its resulting low density causes a smaller quantity to be drawn into the compressor with each stroke.

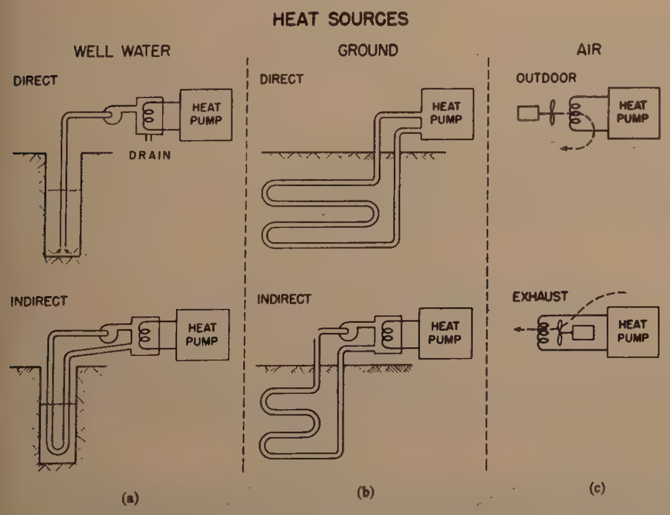

Fig. 14. Principal heat sources

Above the rating-point temperature shown in Fig. 15, the heat pump must be modulated in some manner to meet the building heating requirement. The easiest method, although not the most efficient, is simply to operate the heat pump on-off under control of a room thermostat. If the pumping capacity of the compressor can be varied, the heat pump virtually can be operated continuously whenever heat is needed and will give the required amount of heat at all times. In addition to increased comfort, continuous modulation can provide a substantial increase in average coefficient of performance since the heat pump will run a large portion of the time at reduced capacity, requiring a smaller temperature spread between evaporator and condenser. An important additional benefit will accrue in an increase in electrical load factor.(9) Load factor is the ratio of actual kw-hr used to the kw-hr that would be used with continuous use of maximum demand, and it greatly influences the cost of supplying electricity. Continuous modulation will reduce the maximum power demand to that required at or near the rating temperature.

A view of the typical cooling characteristics on the right-hand side in Fig. 15 shows the previously mentioned discrepancy that may occur between heating and cooling demand. When such a discrepancy exists, consideration may be given to the use of a smaller heat pump with supplementary heating during periods of low temperature. One very intriguing possibility is the storing of some of the excess heating capacity during periods of mild temperature.

Numerous other problems exist in the design of heat pumps and they call for careful analysis and intelligent planning. Electric motor application, controls, refrigeration circuits, heat-transfer surfaces, fans and fluid flow, thermal insulation—and other technical fields—all require detailed consideration.

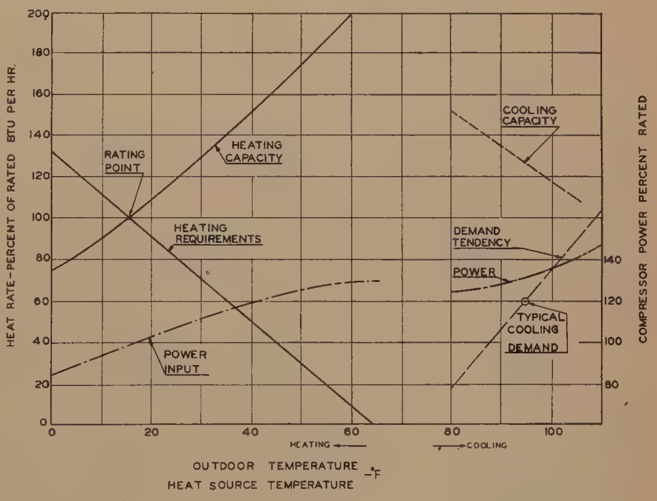

Fig. 15. Heat-pump performance characteristics

Heat-pump application requires expert care and attention. To obtain the maximum benefits from such an installation, proper attention must be given to such matters as duct design and air distribution suitable for both heating and cooling. Since the heat pump works most efficiently with a low condensing temperature, greater air quantities at lower temperatures than are normally encountered with conventional heating systems are utilized.

Perhaps the problem that requires the greatest design skill is that of obtaining complete reliability. A heat pump may operate from 3000 to 7000 hr a year, and a service-free life of a number of years is required.

FUTURE DEVELOPMENT

Although it is still early to obtain a clear-cut picture of what the future holds for the heat pump, it appears to be entering the period of rapid growth, and heat pumps for year-round air conditioning in homes and other buildings will be appearing in greatly increasing numbers. Applications of the heat-pump principle to industrial processes, as well as for water heating, will also emerge in greater numbers. Residential applications will principally be made with self-contained units, and will initially find most rapid acceptance in the southern and west-coast regions. As further technical refinements are made, and as greater consumer familiarity with its advantages is achieved, the growth will spread to the northern and central United States.

It is sometimes refreshing, even if premature, to exercise the imagination by looking further into the future. The *Frontispiece* shows one conception of a "dream" version heat pump. Here the heat pump is combined with some of the multitudinous equipment which our living standards demand in a single factory-produced package. Such a unit would serve as a complete utility core for the house and would provide a source of hot and cold water, conditioned air the year round, and heating and cooling for the associated appliances. Heat that is pumped from the freezing and cold storage compartments would be used to help heat the air and domestic water. Heat that is otherwise wasted in the kitchen exhaust and for evaporating moisture in clothes drying could be largely recovered. The heat pump, thereby, may serve some day as the central unit of the all-electric home.

The more immediate future should see accelerated efforts devoted to two main activities pertaining to the heat pump for year-round air conditioning. One is continued technical effort required to refine the heat pump to achieve the objectives outlined, and the other is the commercial activity needed to obtain consumer acceptance and wide distribution. Achieving the goal will require co-operative participation between manufacturers, utilities, research institutions, contractors, dealers, builders, architects, and engineers.

ACKNOWLEDGMENTS

The author wishes to thank Hotpoint Inc. for permission to use Fig. 6, the Appalachian Electric Power Co. for Fig. 1, the Narragansett Electric Company for Fig. 12, the Ohio Power Co. for Fig. 13, the Joint Heat Pump Committee of the Edison Electric Institute and Association of Edison Illuminating Companies for statistics on heat-pump installations, and his associates in the General Electric Co. for their contributions.

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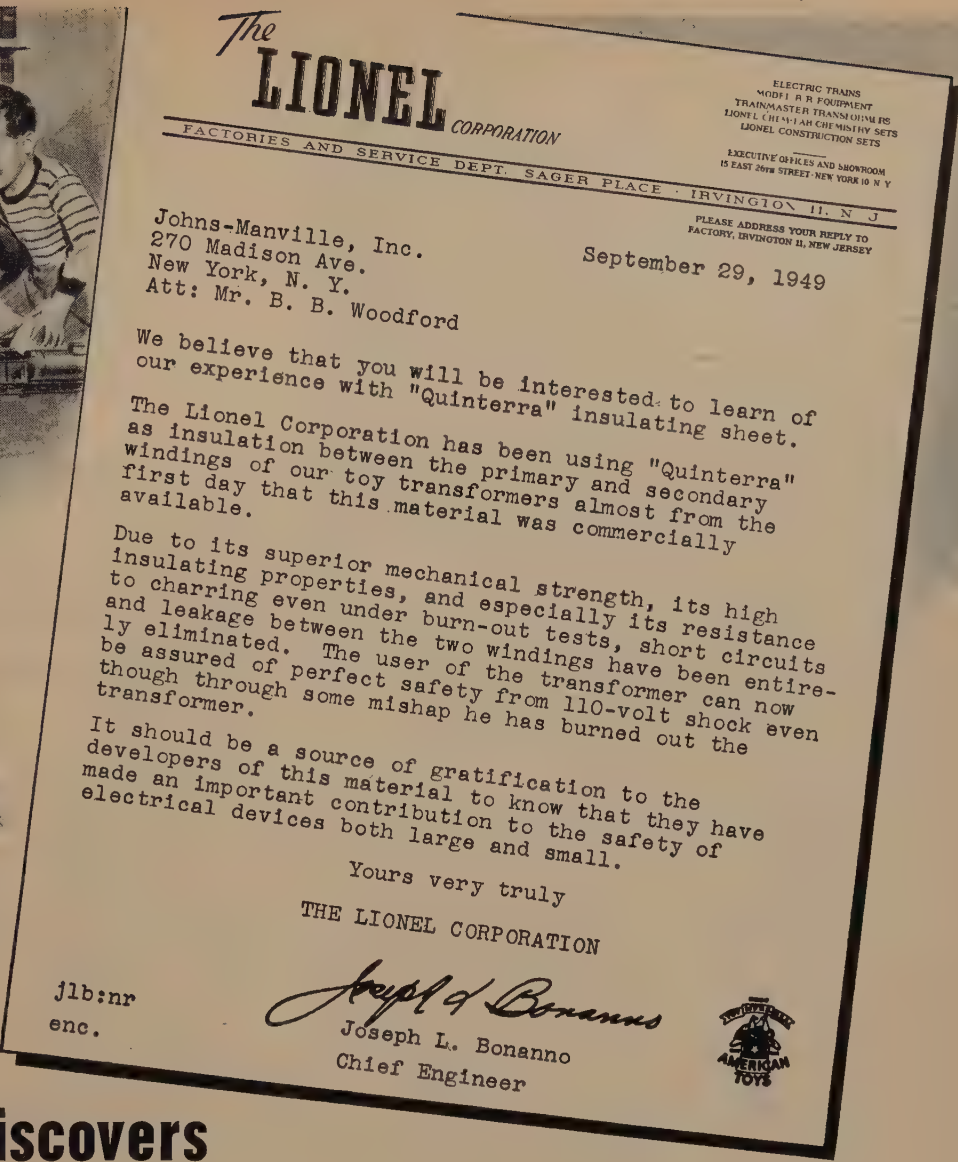

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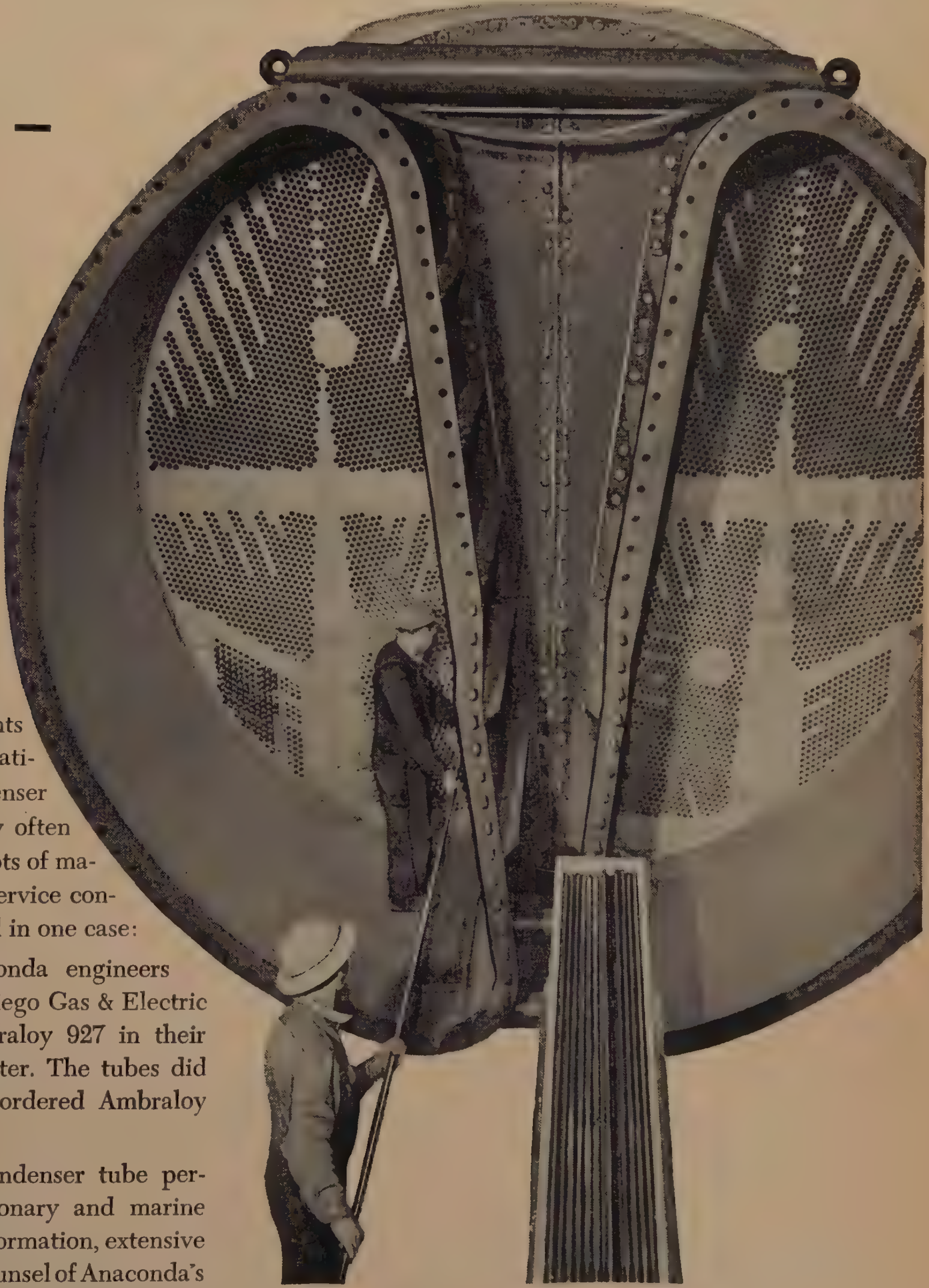

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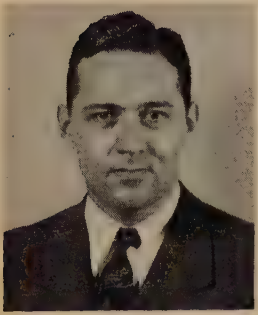

I.B. Johnson

Unusual field experiences, verified and analyzed with transient analyzer, point the way to a more effective design and application of power system apparatus

By I. B. JOHNSON and JOHN BERDY
Analytical Division, Apparatus Department
General Electric Company

John Berdy

MAGNIFICATION of transient voltages in one part of an electric power system may occur in another part of that system, possibly at a different voltage level. Experiences such as this have been obtained from the field: a relatively large number of arrester operations occurred at one voltage level due to switching in another arrester-protected part of the system at another voltage level. Although such occurrences appear to be rarities dependent upon certain circuit configurations and parameter values, they nevertheless are significant in the application and performance of circuit breakers, in the application of arresters, and in the protection of all parts of the system from overvoltages. They are significant also, as the following analysis will indicate, in the application of shunt capacitor banks.

TRANSIENT ANALYZER STUDIES

Under what conditions, then, will voltage magnification take place and what will be the nature of the magnification? To answer these questions, several transient analyzer$^{(1)}$ studies have been made. The first of these is illustrated by the schematic diagram (Fig. 1) of a case where energization and de-energization of a capacitor bank C_1 is being performed. The capacitor bank C_1 is being energized from an infinite bus through some system reactance L_1. Connected to the capacitor bank C_1 is another capacitor bank C_2 (possibly at another voltage level) through some inductive reactance as represented by the delta-wye transformer bank

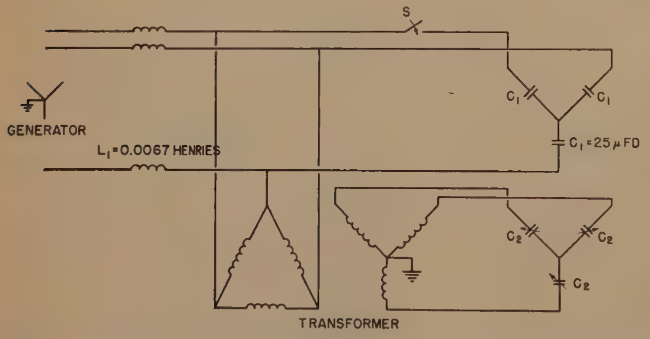

Fig. 1. Schematic diagram illustrating the energizing of a capacitor bank. Circuit for miniature systems study on transit analyzer

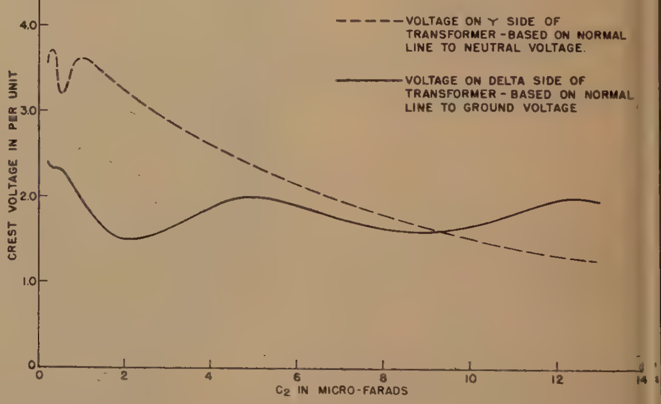

Fig. 2. Maximum voltage across C_2 (Fig. 1) for one restrike versus magnitude of capacitance C_2

The delta-wye transformer bank is composed of miniature single-phase 1:1 transformers whose saturation characteristics at 100 base volts, 60 cycles, approximate those of modern power transformers employing the newer high-silicon steels. The values of L_1 and C_1 used in the study are shown in Fig. 1; C_2 was varied; and the through 60-cycle reactance of one of the single-phase transformers is 18 ohms at 60 cycles.

The circuit shown in Fig. 1 was studied under the following conditions: (1) one phase closing after two phases had already closed; (2) one phase interrupting the charging current to one leg of the capacitor bank C_1 and then restriking,$^{(2)(3)}$ keeping the other phases closed.

For each of these conditions the voltages to ground on all three phases on both sides of the transformer were observed. The resulting transient voltages for

This article is so paged that, without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—Editor

condition (2) from one restrike are plotted in FIG. 2. The voltages are given in per unit of normal line-to-ground voltage on the delta side of the transformer and in per unit of normal line-to-neutral voltage on the wye side of the transformer as a function of the capacitance C_2. These voltages are the maximum obtainable on any one phase on each side of the transformer bank.

---

(1)Numbered references are listed at the end of the article.

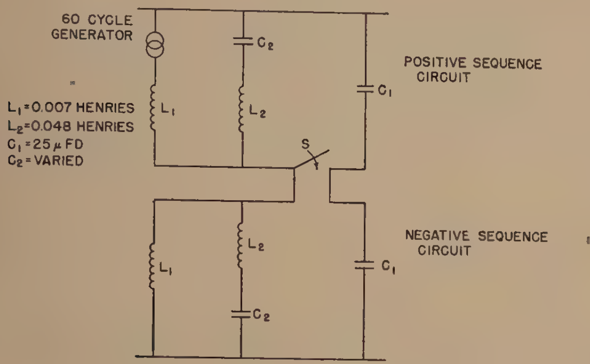

Fig. 3. Equivalent sequence circuits for Fig. 1

Thus, in per unit, as shown by the curves in FIG. 2, the voltages on the wye side of the transformer exceed those on the delta side for small values of capacitance C_2 where, for example, with $C_2=0.3$ μfd, the per unit values are 3.7 and 2.3 respectively. Similarly for condition (1) with a switch-closing operation on one phase, the results are plotted as the dashed curve in FIG. 4. It is noted in comparison that for $C_2=0.3$ μfd, the voltages, in per unit, on the wye and delta sides of the transformer are 2.4 and 1.83 respectively. These results, in general, confirm some experiences from the field.

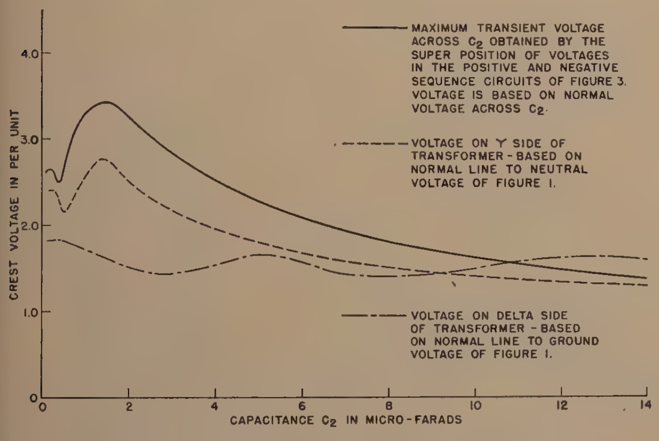

Fig. 4. Maximum voltage across C_2 energizing C_1 versus magnitude of C_2

SIMPLIFIED CIRCUIT STUDIES

On a steady-state basis, the equivalent sequence circuit of FIG. 1 is given in FIG. 3, showing the positive and negative sequence circuits and the interconnection between them to represent the open-phase condition.⁽⁴⁾ If in the circuit shown in FIG. 3 the switch S is closed, a transient condition will occur in both the positive and the negative sequence circuits. By superimposing the transient voltages across C_2 from both the positive and the negative sequence circuits on the steady-state voltage across C_2, the resulting transient voltage across the capacitor C_2 is obtained. For the closing of switch S at the instant that produced the maximum transient voltages, the results are plotted as the solid curve in FIG. 4. Comparing the solid curve with the dashed curve as obtained from the circuit shown in FIG. 1, a close correlation is evident, considering the fact that each of the values of L_2 and C_2 used in FIG. 3 corresponds to a higher impedance level than the corresponding values in FIG. 1.

Basically, as indicated by the equivalent sequence circuits, it appears that an idealized circuit to be considered in voltage-magnification processes is the double-energy circuit shown in FIG. 5. In the study of this circuit, the switching was done so as to energize the complete circuit with zero initial charges and currents from essentially a d-c source in contrast to the previous studies of shocking the circuit under initial conditions of charges and currents. The transient analyzer results are plotted as a dashed curve in FIG. 6 giving maximum transient voltage across C_2 in per unit of the applied voltage as a function of the capacitance ratio C_1/C_2. These results are based on L_1C_1 approximately equal to L_2C_2.

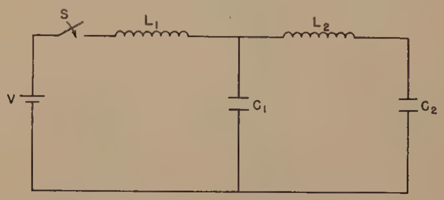

Fig. 5. Idealized circuit for analyzing voltage magnification in the double-energy circuit

The solid curves in FIG. 6 were calculated from the equations accompanying the curves and indicate the trend as the L_1C_1 product becomes different from the

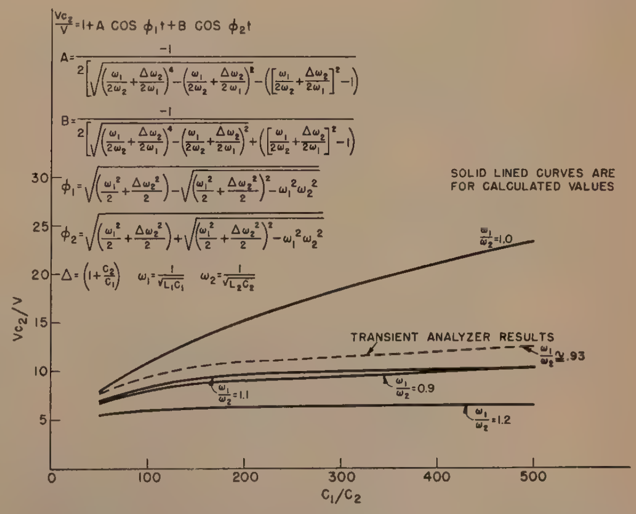

Fig. 6. Ratio of maximum voltage across C_2 to input voltage, when circuit in Fig. 5 is energized, versus the ratio C_1/C_2

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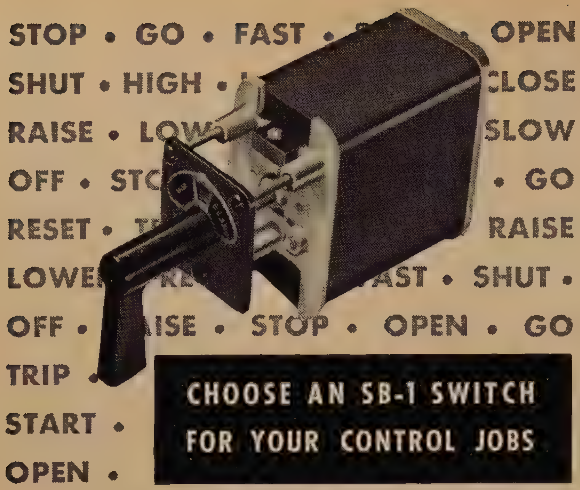

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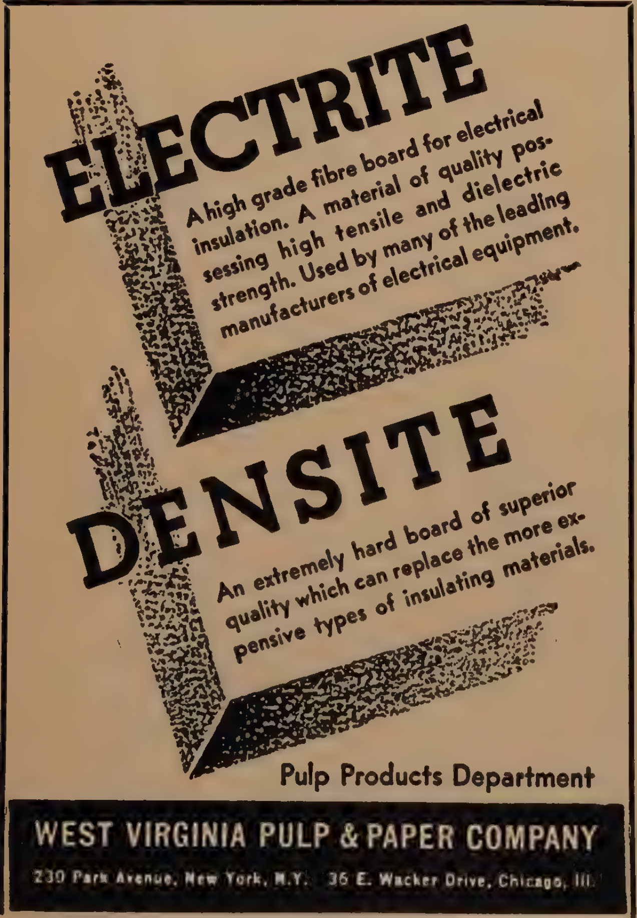
GENERAL ELECTRIC
850-21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MAGNIFICATION OF SWITCHING OVERVOLTAGE

(Continued from preceding page)

L_2C_2 product. The curves were obtained by adding in phase the maximum values from the three component terms in the equation.

CONCLUSIONS

(1). Confirming some experiences from the field, transient analyzer studies indicate that magnification of transient voltages occurring in one part of an electric system may occur in another part of that system, possibly at a different voltage level, under certain conditions involving coupled double-energy circuits.

(2). In coupled double-energy circuits where voltage magnification is possible, there is an increased desirability that the circuit breakers used in switching the capacitors have a minimum or no tendency to restrike on interrupting charging current in order not to increase the probability of increasing the magnitude of the voltage magnification.

(3). In the increasing application of capacitors in power systems, the increased need for arresters and reliance on them to limit switching surge over-voltages as well as lightning surges in protecting apparatus in all parts of the system is demonstrated.

(4). Based on the circuits considered, consisting essentially of two coupled double-energy circuits, the voltage magnification appears to be greatest when the L_1C_1 product of the first circuit in which the switching occurs is approximately of the order of the L_2C_2 product of the second circuit and when, in addition, the capacitance C_1 in the first circuit is appreciably greater than the capacitance C_2 in the second circuit across which the voltage magnification occurs.

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(3)"Switching High-voltage Transmission Lines," by I. B. Johnson and J. R. Wilson. *AIEE Transactions*, vol. 66, 1947, pp. 155-260.

(4)Edith Clarke: *Circuit Analysis of A-c Power Systems*, John Wiley and Sons, Inc., New York, New York, 1943.

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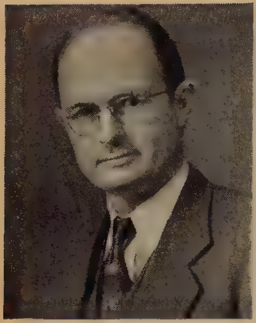
REACTORS IN LOW-VOLTAGE INDUSTRIAL POWER SYSTEMS OF 600 VOLTS OR LESS



D. L. Beeman

The application of a new compact type of current-limiting reactor unit now becomes a convenient means of obtaining short-circuit protection in certain types of installations

L. L. Baird

By D. L. BEEMAN and L. L. BAIRD
Industrial Engineering Divisions Switchgear Divisions
General Electric Company

MOST power system engineers look unfavorably upon the use of reactors, particularly in low-voltage industrial power systems (600 volts or less), because of their inherent disadvantages, namely:

(1) voltage drop; (2) power loss; (3) cost; (4) space.

However, reactors properly applied in low-voltage systems can be a useful tool for obtaining adequate short-circuit protection where without the added reactance short-circuit currents would be beyond the interrupting ability of reasonable-sized equipment. On the other hand, reactors are too often thought of as a way to cut down the interrupting duty and thus reduce the cost of the switching equipment in a main switchboard. This is, in general, an improper and uneconomical application of reactors in low-voltage systems. Thus, there are both proper and improper applications in low-voltage systems.

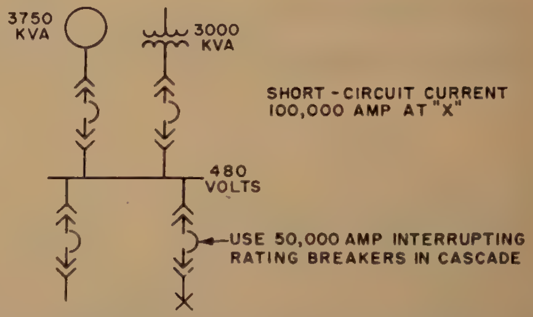

3750 KVA
3000 KVA
SHORT - CIRCUIT CURRENT 100,000 AMP AT "X"
480 VOLTS
USE 50,000 AMP INTERRUPTING RATING BREAKERS IN CASCADE

Fig. 1b. Distribution system utilizing cascaded breakers may be used instead of the system in Fig. 1a, but it has not some of the advantages of the latter

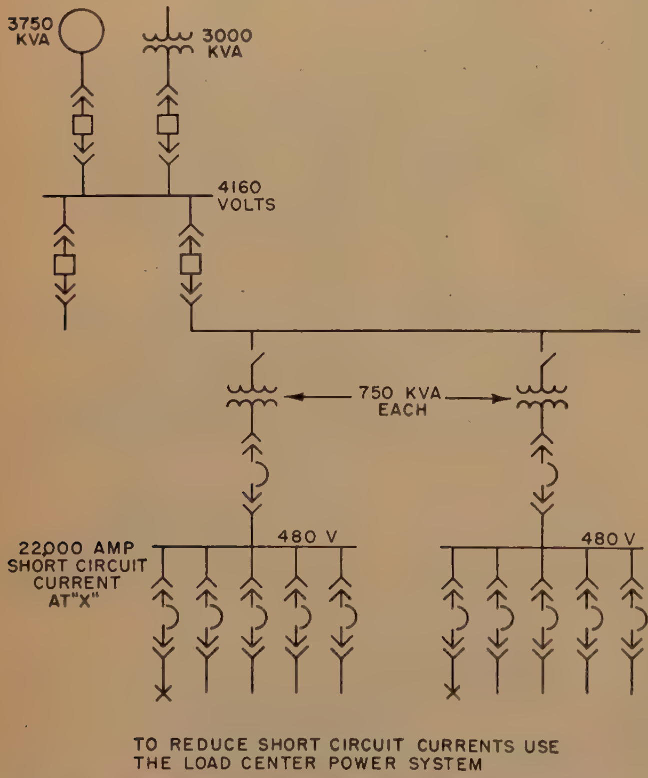

3750 KVA
3000 KVA
4160 VOLTS
750 KVA EACH
480 V
480 V
22,000 AMP SHORT CIRCUIT CURRENT AT "X"
TO REDUCE SHORT CIRCUIT CURRENTS USE THE LOAD CENTER POWER SYSTEM

Fig. 1a. Load-center system subject to inherently low short-circuit currents

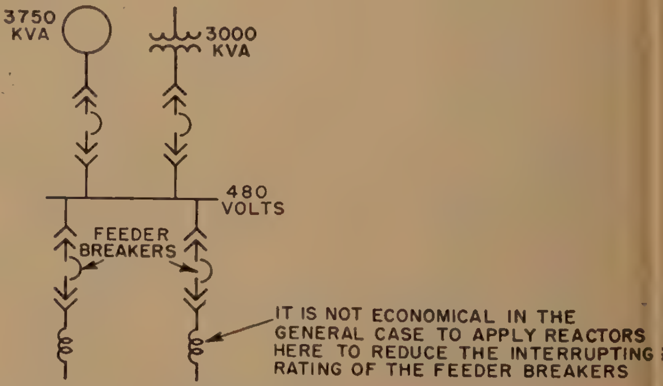

3750 KVA
3000 KVA
480 VOLTS
FEEDER BREAKERS
IT IS NOT ECONOMICAL IN THE GENERAL CASE TO APPLY REACTORS HERE TO REDUCE THE INTERRUPTING RATING OF THE FEEDER BREAKERS

Fig. 1c. Feeder arrangement with reactors on load side for the purpose shown here is an example of improper reactor application

IMPROPER REACTOR APPLICATIONS

First, it will be well to show what improper applications are, to forestall misinterpretation of the applications that are considered later.

In general, a 15,000- or 25,000-amp interrupting rating breaker plus a reactor is more expensive than a

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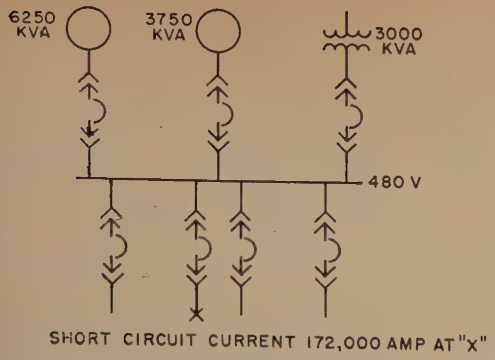


Fig. 2a. An instance in which a large reactor can be used effectively: the short-circuit exceeds 100,000 amp

50,000-amp circuit breaker. For example, one would not apply a 15,000-amp interrupting breaker plus a reactor in any place where a 50,000-amp breaker would give adequate protection to all parts of the circuit. In addition to costing more in this application, the two units add voltage drop and losses and require more space. Moreover, reactors should not be applied just to attempt to reduce the cost of a main switchboard. Therefore, when a problem of applying switchgear to a large low-voltage system arises, it is good practice to adopt a load-center system with inherently low short-circuit currents as shown in Fig. 1a, or, if the load center system cannot be adopted, to use cascaded breakers as shown in Fig. 1b. The load-center system is lower in cost and has technical advantages over the system shown in Fig. 1c.

APPLICATIONS FOR LARGE, LOW-VOLTAGE REACTORS

If reactors are used, they should preferably be placed in small branch circuits to reduce voltage drop. However, there is one exception in which large reactors can be applied effectively and that is where the total short-circuit current in a low-voltage system without reactors is over 100,000 amp, as in Fig. 2a. There is no standard a-c switchgear available to handle short circuits in excess of 100,000 amp. In such cases the proper engineering solution is found in a load-center system; but where conditions do not permit the adoption of the load-center system immediately, and something must be done to reduce short-circuit currents, then large reactors can be effectively applied in a synchronizing bus as shown in Fig. 2b.

APPLICATIONS FOR SMALL, LOW-VOLTAGE REACTORS (600 AMP AND LESS)

Small reactors find certain applications in low-voltage systems, the most notable of which are in commercial buildings fed from large secondary network systems, having available short-circuit currents of approximately 50,000 to 100,000 amp. To obtain adequate protection at a reasonable cost, cascading of circuit breakers is used. The main switchboard one-line diagram for such a building may be like that shown in Fig. 3. The switchgear is adequate from an interrupting standpoint. The feeder breakers are cascaded with the main breakers.

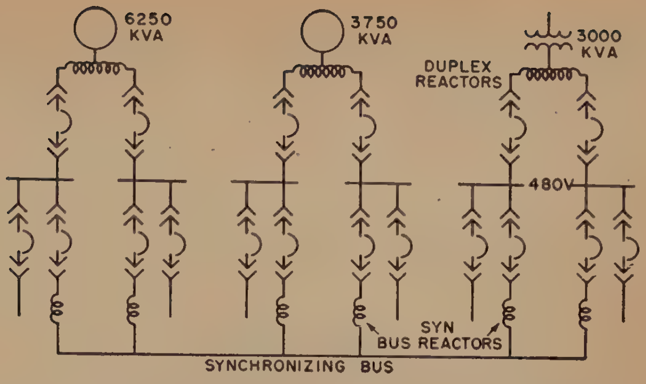


Fig. 2b. An example of the use of large reactors in a low-voltage system, for reducing short-circuit currents to a value within the rating of available switchgear

In most buildings there are three conditions which cannot be met either economically or technically by the arrangement shown in Fig. 3. They are:

(1). Small circuit ahead of main breaker for fire pump or emergency lights. Circuit breakers for these cannot be cascaded as they are ahead of the main breaker and usually have small ampere ratings so that the trip coils will not withstand the available short-circuit current. Because of the small current only small cable, say No. 1/0 Awg, is required. This size cable, for example, will withstand only 35,000 amp short-circuit current.

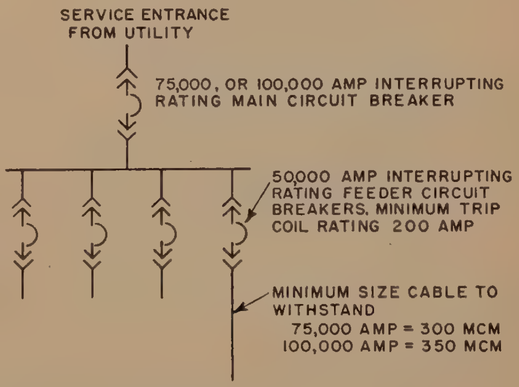

SERVICE ENTRANCE FROM UTILITY
75,000, OR 100,000 AMP INTERRUPTING RATING MAIN CIRCUIT BREAKER
50,000 AMP INTERRUPTING RATING FEEDER CIRCUIT BREAKERS. MINIMUM TRIP COIL RATING 200 AMP
MINIMUM SIZE CABLE TO WITHSTAND
75,000 AMP = 300 MCM
100,000 AMP = 350 MCM

Fig. 3. Main switchboard for a large commercial building suitable for available short-circuit currents up to 100,000 amp RMS asymmetrical

(2). Panelboards too close to the main switchboard to have the benefit of the cable impedance to reduce short-circuit current to within their interrupting rating.

With 75,000 amp available, it takes about 125 ft of 300 MCM cable and with 100,000 amp available it takes about 150 ft of 350 MCM cable to reduce the short-circuit current at 208Y/120 volts to where 15,000-amp panelboards could be used within their interrupting rating.

(3). There may be small local circuits which would require breaker trip coils of smaller rating than could withstand the short-circuit current available.

These conditions are illustrated in FIG. 4. To use a 100,000-amp "IC" (interrupting capacity) breaker for the 100-amp fire-pump circuit would be economically unreasonable. Also it is not feasible from a practical standpoint to put a 100-amp trip coil on such a breaker. The 50-amp trip coil on the right-hand breaker (FIG. 4) will not withstand the short-circuit current. Also a very much oversize wire in the cable circuit would be required. The first panelboard on the left-hand feeder would be overstressed from the short-circuit current standpoint.

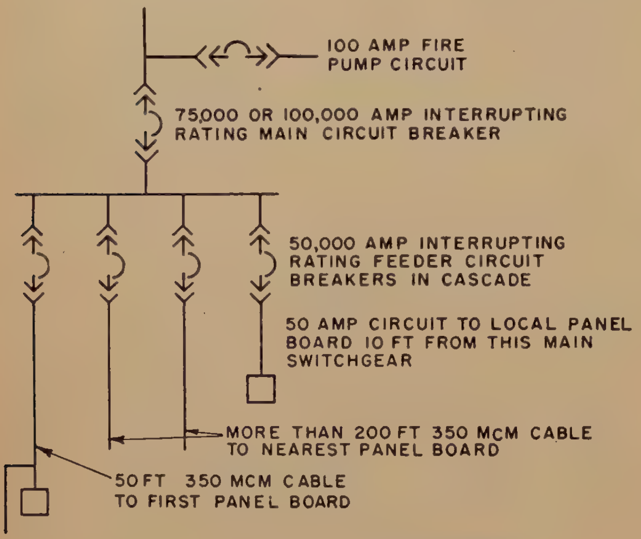

100 AMP FIRE PUMP CIRCUIT
75,000 OR 100,000 AMP INTERRUPTING RATING MAIN CIRCUIT BREAKER
50,000 AMP INTERRUPTING RATING FEEDER CIRCUIT BREAKERS IN CASCADE
50 AMP CIRCUIT TO LOCAL PANEL BOARD 10 FT FROM THIS MAIN SWITCHGEAR
MORE THAN 200 FT 350 MCM CABLE TO NEAREST PANEL BOARD
50 FT 350 MCM CABLE TO FIRST PANEL BOARD

Fig. 4. Circuit condition in a typical building

The application of current-limiting reactors in these three cases provides an economical and technically sound answer to the problem of obtaining adequate short-circuit protection. Reactors would be applied as shown in FIG. 5.

APPLICATION OF REACTOR IN INDUSTRIAL SYSTEMS

Industrial-plant power systems lend themselves to the use of the load-center power systems which have inherently low short-circuit currents. For example, a 750-kva 480-volt load-center substation has a maximum short-circuit current of under 25,000 amp, which permits the application of a standard combination motor starter and small circuit breakers. The bus and cable has a 25,000-amp interrupting rating or short-circuit current withstand ability.

Where excessively high short circuits are encountered in old large low-voltage systems, the application of reactors would in most cases be considered less desirable than modernizing with a load-center power system. Also, in commercial buildings where it is necessary to use reactors, the application principles would be the same as those outlined.

Occasionally reactors may find reasonable application in load-center unit substations for small circuits for fire pumps or emergency lights taken off ahead of the main circuit breaker or to protect equipment on the feeders. This is shown in FIG. 6a.

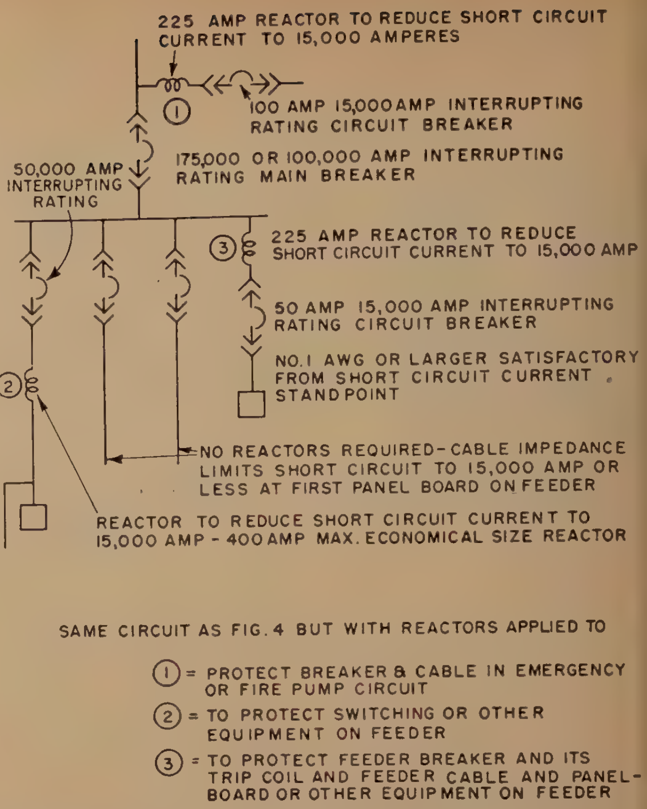

225 AMP REACTOR TO REDUCE SHORT CIRCUIT CURRENT TO 15,000 AMPERES
①
100 AMP 15,000 AMP INTERRUPTING RATING CIRCUIT BREAKER
50,000 AMP INTERRUPTING RATING
175,000 OR 100,000 AMP INTERRUPTING RATING MAIN BREAKER
③
225 AMP REACTOR TO REDUCE SHORT CIRCUIT CURRENT TO 15,000 AMP
50 AMP 15,000 AMP INTERRUPTING RATING CIRCUIT BREAKER
NO. 1 AWG OR LARGER SATISFACTORY FROM SHORT CIRCUIT CURRENT STANDPOINT
②
NO REACTORS REQUIRED - CABLE IMPEDANCE LIMITS SHORT CIRCUIT TO 15,000 AMP OR LESS AT FIRST PANEL BOARD ON FEEDER
REACTOR TO REDUCE SHORT CIRCUIT CURRENT TO 15,000 AMP - 400 AMP MAX. ECONOMICAL SIZE REACTOR
SAME CIRCUIT AS FIG. 4 BUT WITH REACTORS APPLIED TO
① = PROTECT BREAKER & CABLE IN EMERGENCY OR FIRE PUMP CIRCUIT
② = TO PROTECT SWITCHING OR OTHER EQUIPMENT ON FEEDER
③ = TO PROTECT FEEDER BREAKER AND ITS TRIP COIL AND FEEDER CABLE AND PANEL-BOARD OR OTHER EQUIPMENT ON FEEDER

Fig. 5. Application of reactors for obtaining protection from short circuits

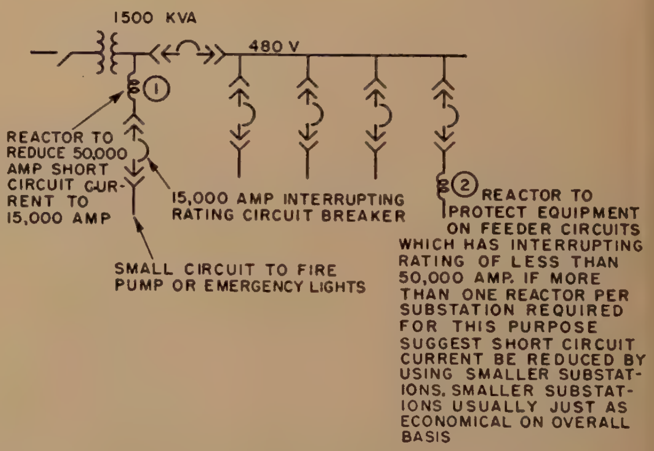

1500 KVA
480 V
①
REACTOR TO REDUCE 50,000 AMP SHORT CIRCUIT CURRENT TO 15,000 AMP
15,000 AMP INTERRUPTING RATING CIRCUIT BREAKER
SMALL CIRCUIT TO FIRE PUMP OR EMERGENCY LIGHTS
② REACTOR TO PROTECT EQUIPMENT ON FEEDER CIRCUITS WHICH HAS INTERRUPTING RATING OF LESS THAN 50,000 AMP. IF MORE THAN ONE REACTOR PER SUBSTATION REQUIRED FOR THIS PURPOSE SUGGEST SHORT CIRCUIT CURRENT BE REDUCED BY USING SMALLER SUBSTATIONS. SMALLER SUBSTATIONS USUALLY JUST AS ECONOMICAL ON OVERALL BASIS

Fig. 6a. Application of reactors to load-center circuits should not often be required; but in circumstances such as these, reactors may be used beneficially

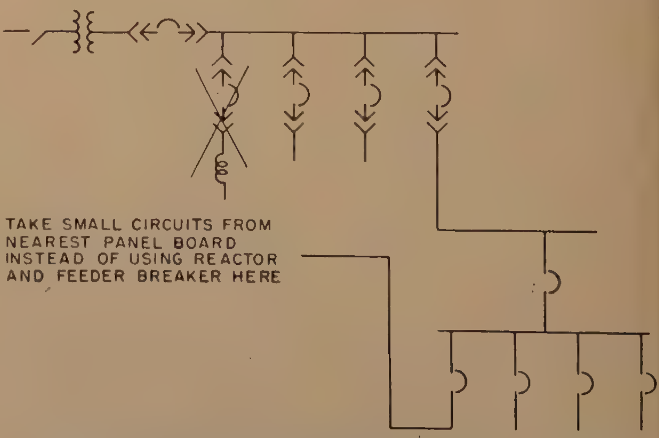

TAKE SMALL CIRCUITS FROM NEAREST PANEL BOARD INSTEAD OF USING REACTOR AND FEEDER BREAKER HERE

Fig. 6b. Diagram of proper arrangement of low-current circuits to protect small breakers without use of a reactor

There seems to be little need for reactors to protect small breakers for low ampere rating circuits taken off unit substations on the load side of the main circuit breaker. Small circuits should be taken from the nearest distribution panel (Fig. 6b).

Current-limiting Reactors

AVAILABLE REACTORS

Until recently, there had been no current-limiting reactors available that were designed specifically for low-voltage circuits (600 volts and below). Reactors generally available for such applications were of the coiled-cable cast-concrete type. These were not as economical of space as desired and did not lend themselves to being mounted readily in low-voltage metal-enclosed equipment. A new three-phase reactor* designed for use in metal enclosures in circuits of 600 volts and below is shown in Figs. 7 and 8. It can be obtained in single-phase as well as three-phase units.

REACTOR DESIGN

Each coil is made by winding a bare rectangular-cross-section conductor in a spiral around a central insulating core. A double layer of impregnated asbestos paper of 20 mil thickness is used for turn insulation in the coils. The coils for the three phases are then clamped together between sheets of heavy insulating compound, by large through tie-bolts. The outer turn of each coil is extended to serve as a terminal. A conductor is brazed to the center of the coil to serve as the other terminal of each phase. Fig. 9 is a view of the reactor with one end plate removed, showing the coil construction.

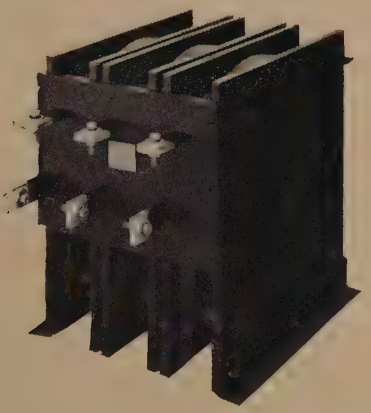
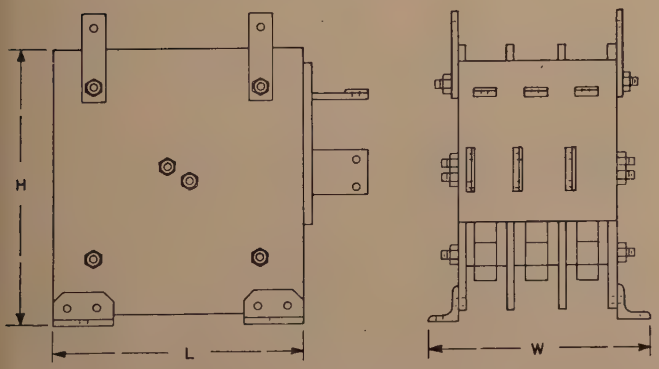


Fig. 7. New three-phase reactor designed for low-voltage use in metal enclosures



RATING	H	L	W
225	18	17	$14\frac{1}{2}$ TO 18
400 & 600	22	22	17 TO 20

Fig. 8. Outlines and approximate dimensions of reactors of the type shown in Fig. 7

This type of construction has resulted in a compact reactor which will withstand the short-circuit stresses with available currents as high as 100,000 amp.

When the incoming power is connected to similar terminals on all phases and the outgoing power to the other similar terminals on all phases, the phase-to-ground and line-to-line impedances are greater than the published three-phase impedances. This impedance ratio varies between 1.1 and 1.4 for the reactor design shown in Figs. 7 and 8 and is dependent upon the phase spacing and the number of coil turns. When the phase spacing is small and the number of coil turns large, this single-phase to three-phase impedance ratio is highest. Thus, when the reactors are applied on the basis of three-phase calculations, they possess a safety factor for connected equipment on single-phase faults. This is desirable, but it complicates the reactor design since it produces short-circuit forces tending to separate the coils of adjacent phases. Calculations show that a total force as high as 12 tons acts between adjacent phases to force them apart. This force varies from zero to maximum every half-cycle. Adequate design tests have been made to be certain that the reactor construction is such that it will withstand these forces.

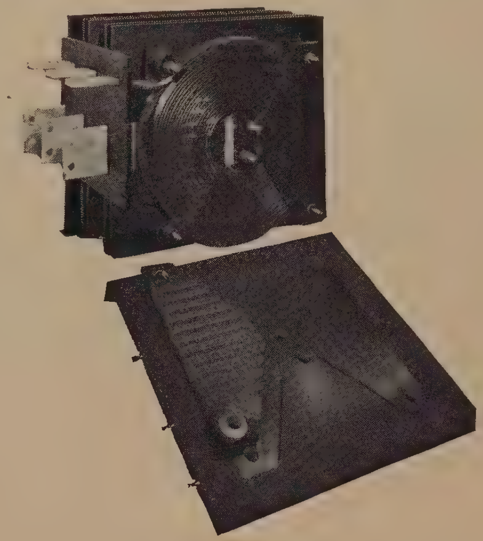


Fig. 9. Reactor with plate removed to show internal construction of the new unit

Although it is desirable for reactors to be as small as possible, there are several factors which limit the phase spacing which may be used. As the phase spacing is decreased, the short-circuit forces in the reactor increase, the three-phase impedance decreases, and it becomes more difficult to provide the necessary ventilation for the conductors.

---

*This current-limiting reactor bears the trade designation Type RM-1.

The phase spacing in the reactors has been reduced as much as possible consistent with the other factors involved. Because of the close proximity of adjacent turns and adjacent phases necessary to reduce the physical sizes of the reactors, the a-c resistance is between two and eight times the d-c resistance, using copper for the conductor. It varies depending upon the number of turns and the phase spacing. About 80 percent of this difference in a-c and d-c resistance ratio is due to eddy current losses in the turns.

Since the a-c/d-c resistance ratio with copper conductor is high, it has been possible to use aluminum instead of copper as the conductor on all reactors except the 600-ampere size with the highest number of turns. The conductivity of aluminum is only 60 percent of that of copper when used volume for volume in place of copper. If the resistivity alone is considered, it would seem apparent that the temperature rise attained in using aluminum would be considerably higher than when using copper. However, aluminum as the conductor gives only a very small increase in heating over that with copper. This is due mainly to the lower eddy current losses in the higher-resistivity material. The use of aluminum results in a lighter-weight and lower-cost reactor in those sizes where it can be used.

A special terminal connection is furnished for reactors using aluminum conductor material. When copper or silver-plated copper parts are connected to aluminum there is always a possibility of corrosion in humid atmospheres due to electrolytic action between the two materials. A special aluminum-copper sheet is used to make the connection. In this material the bond is made without the use of solder or flux. The aluminum surfaces are first cleaned and coated with a special protective grease. The aluminum surface of the sheet is placed against the aluminum terminal and temporarily bolted in place for shipment purposes. The copper surface of the sheet is given a plating of silver for a permanent low-resistance connection to the user's cable or bus work. This type of terminal has been given temperature-rise, short-circuit, and weathering tests to determine its suitability.

REACTOR TESTS

All reactors are given a turn-to-turn high-potential test at 450 kilocycles. At this high frequency the impedance of each coil is large enough to allow sufficient voltage to be developed between turns to test the turn insulation. A 60-cycle high-potential test is also made on each reactor to test the phase insulation.

PROBLEMS IN SELECTING AND APPLYING REACTORS

The manufacturers should be consulted for ratings and characteristics of available reactors for mounting in metal-clad drawout switchgear. However, Table I shows representative ratings and reactor characteristics.

The following are some of the considerations which led to choice of ratings in Table I and indicate how

TABLE I

REPRESENTATIVE RATINGS AND OPERATING CHARACTERISTICS OF TYPICAL AVAILABLE REACTORS

Item No.	E	I	Interrupting Capacity "IC"		Required 60-cycle X/Phase (Ohms)	Actual 60-cycle X/Phase (Ohms)	Operating Condition				
			Line (Maximum)	Output			E	I	Percent Voltage Drop at Normal Power Factor		
									0.8	0.85	0.9
1a	240	225	100,000	15,000	0.00982	0.0126	240 216	225 225	1.57 1.71	1.44 1.58	1.24 1.40
1b	240	225	25,000	15,000	0.00461	0.00620	240 216	225 225	0.77 0.84	0.70 0.77	0.60 0.68
2	240	400	100,000	15,000	0.00982	0.00980	240 216	400 400	2.17 2.40	1.97 2.20	1.75 1.92
3	240	400	25,000	15,000	0.00462	0.00500	240 216	400 400	1.11 1.23	1.00 1.11	0.88 0.97
4	240	600	100,000	25,000	0.0052	0.00650	240 216	600 600	2.19 2.41	1.94 2.16	1.70 1.90
5	240	600	50,000	25,000	0.0035	0.0035	240 216	600 600	1.16 1.29	1.05 1.17	0.92 1.03
6a	480	225	75,000	15,000	0.0185	0.0264	480	225	1.66	1.50	1.30
6b	480	225	25,000	15,000	0.0093	0.0126	480	225	0.77	0.72	0.62
7	480	400	75,000	25,000	0.0093	0.00980	480	400	1.07	0.98	0.86
8	480	400	25,000	15,000	0.0092	0.00980	480	400	1.07	0.98	0.86
9	480	600	75,000	25,000	0.0093	0.00930	480	600	1.54	1.43	1.24
10	480	600	50,000	25,000	0.0070	0.0093	480	600	1.54	1.43	1.24

Output is with maximum line short-circuit amperes available. At lower values of available line short-circuit current the output will be lower but not directly proportionally lower because of impedance of remainder of circuit.

reactors for mounting integral with metal-enclosed drawout switchgear should be selected. Reactors for reduction of short-circuit current can be applied most effectively and incur less normal voltage drop if they are used in circuits of small rather than large ampere rating.

It takes the same number of ohms to reduce the short-circuit current from the one level to another regardless of the load current of the circuit. Thus, the smaller the load current the less the voltage drop for a given reduction in short-circuit level. There are also limits as to how far one can go in reducing short circuits for a given circuit without encountering voltage-drop troubles due to motor starting. As a rule for general application the short-circuit current at the source of the feeder should be of the order of 20 times full-load current or more to prevent voltage drop troubles, particularly on lower-power-factor steady-state loads and on motor starting.

Resolving all these factors indicated that reactors for this service should have continuous ratings of not larger than 600 amp and that for 600-amp reactors the short-circuit current should not be limited to less than 25,000 amp. This level of short-circuit current is satisfactory for supplying power apparatus and motor starters with 25,000 amp interrupting rating which are readily available. Therefore, there is no need to go further so far as this class of load apparatus is concerned. The principal application of the 600-amp reactors is in circuits feeding power apparatus using Cabinetrol motor-control centers and combination motor starters on the branch circuit to motors and other power apparatus.

However, lighting circuits are commonly controlled by panelboards of questionable interrupting ability and generally not more than 5000 amp capacity.

Most buildings of any size are fed by combined lighting and power circuits; therefore, the possibility of fairly large motor starting current on a combined lighting and power circuit must be faced. This, coupled with the unwieldy size of a reactor to reduce short-circuit currents from 100,000 to 5000 amp, indicated that it was not practical to go as low as a 5000-amp short-circuit level. However, because it was desirable to go lower than 25,000 amp, two smaller ratings of reactors (namely, 225 and 400 amp) were introduced which limited available short-circuit currents of 100,000 amp to about 15,000 amp, the next established level below 25,000 amp. The 225- and 400-amp reactors are primarily for use in series with breakers feeding combined light and power secondary feeders supplying panelboards.

These ampere ratings are large enough to allow economical-size secondary feeders. Four hundred amperes is the current-carrying capacity of cables of the order of 500 to 750 MCM. This does, however, limit secondary feeder sizes to 400 amp maximum where panelboards are connected to the feeder, and to 600 amp maximum where only combination motor starters rated 25,000 amp or more are connected to a feeder. These are very useful in metal-clad drawout switchgear (Fig. 10) for large buildings served from secondary network systems where short-circuit currents at the service entrance are as high as 100,000 amp. Since reactors are an added cost and require space, they should be used only in those circuits which do not have sufficient cable impedance to limit the fault current to the desired value. Short lengths of cable are very effective in reducing short-circuit currents, particularly in 208Y/120 volt systems.

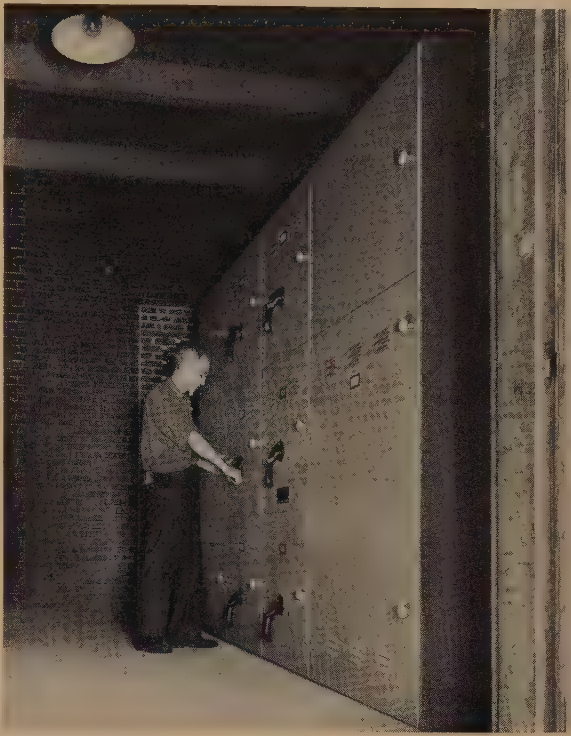


Fig. 10. Metal-enclosed switchboard of type in which new reactors are useful elements for circuit protection

WHERE SHOULD REACTORS BE LOCATED?

These reactors should, wherever possible, be located on the load side of a feeder circuit breaker so that the feeder circuit breaker protects the reactor as well as the feeder circuit. Therefore, whenever reactors are applied to protect cables, panelboards, or other equipment exterior to the metal-clad drawout switchgear, the reactors should be on the load side of the feeder circuit breaker. The feeder circuit breaker should be adequate from an interrupting standpoint considering the reactor *not* in the circuit.

However, when reactors are applied in switchgear to protect the circuit-breaker trip coil where very low trip coil ratings are used or to permit a reasonable-sized breaker to be used, as in a fire-pump circuit taken off ahead of the main incoming-line circuit breaker, the reactors must be located on the bus side of such circuit breakers. It is felt that reactors as supplied with the switchgear are essentially as reliable as the bus yet they represent just that much more exposure on the bus; thus, the application of reactors directly connected to the bus without an intervening breaker should be limited to a minimum.

STEADY-STATE VOLTAGE DROP

In addition to the limitation imposed by ratings of available reactors, certain other effects must be considered when reactors are applied in low-voltage systems. The first is voltage drop under steady-state load. The voltage drop is affected mainly by the power factor of the load, as indicated in FIG. 11. Large circuits at lower power factor will give too great a voltage drop with high-reactance reactors in them. Thus, this is one limit as to how much the short-circuit current can be reduced by reactors. The voltage drops at normal power factors are shown in Table I. For lighting circuits with a power factor of 0.9 or better, the drop at rated load of the reactor averages about 1.5 percent with a maximum of 1.92 percent.

P F	0.5	0.6	0.7	0.8	0.9	1.0
VOLTS DROP	7.5	7.1	6.6	5.9	4.8	1.7
PERCENT DROP AT 480 VOLTS	1.63	1.54	1.44	1.22	1.01	0.3

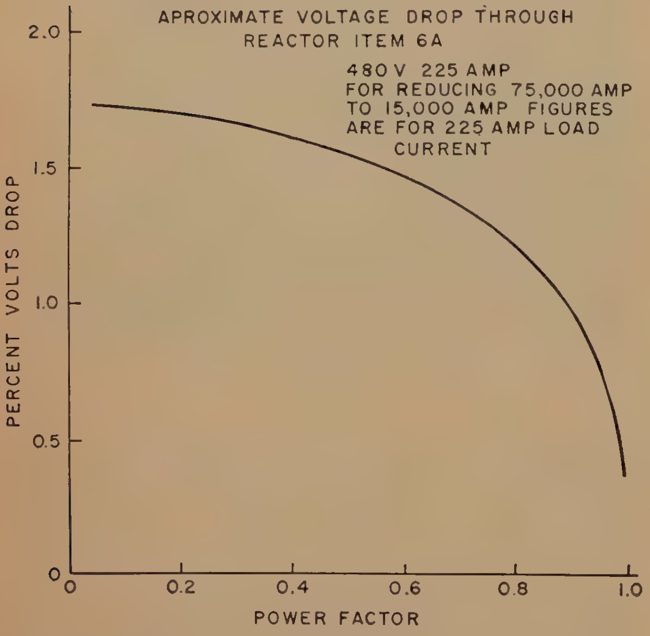


Fig. 11. Voltage drop through a typical reactor, as affected by changes in power factor

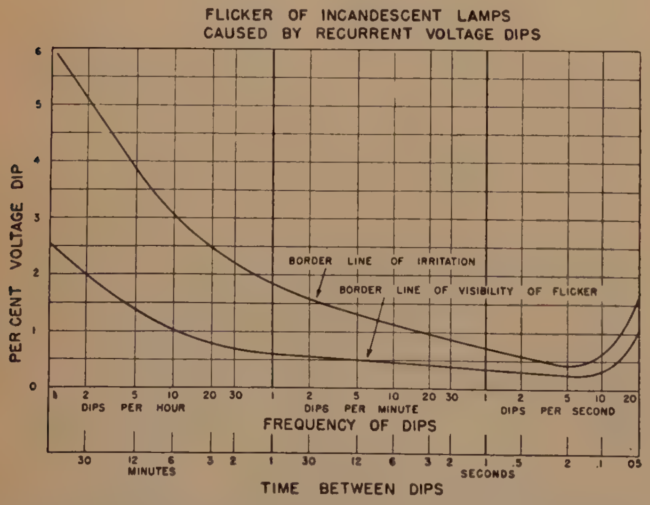


Fig. 12. Flicker curves showing effects of voltage dips upon visibility in incandescent lamps

VOLTAGE DIP ON MOTOR STARTING

Motors draw a large low-power-factor current when starting (Table II). This is about six times normal current at about 30 to 70 percent power factor. The voltage drop due to motor-starting currents can cause a very large voltage drop if there is too much reactance in a circuit. For frequent motor starting, this drop should not be more than a few percent where lights are affected. (FIG. 12 shows a flicker curve.) Where lights are not affected, but other power equipment is, the allowable voltage drop on motor starting may vary from five to as much as ten percent. FIGS. 13 and 14 show the voltage drop caused by various sized motors at 240 or

TABLE II

REPRESENTATIVE MOTOR STARTING CURRENT (AMPERES)

Motor HP	Starting Power Factor	220-volt Motor 208-volt Circuit	220-volt Motor 230-volt Circuit	440-volt Motor 480-volt Circuit
1	0.70	23 amp	26 amp	13 amp
25	0.40	345	382	191
100	0.30	1370	1520	760
200	0.30	2740	3040	1520

Motor characteristics are typical of normal torque, normal starting current, squirrel-cage induction motors.

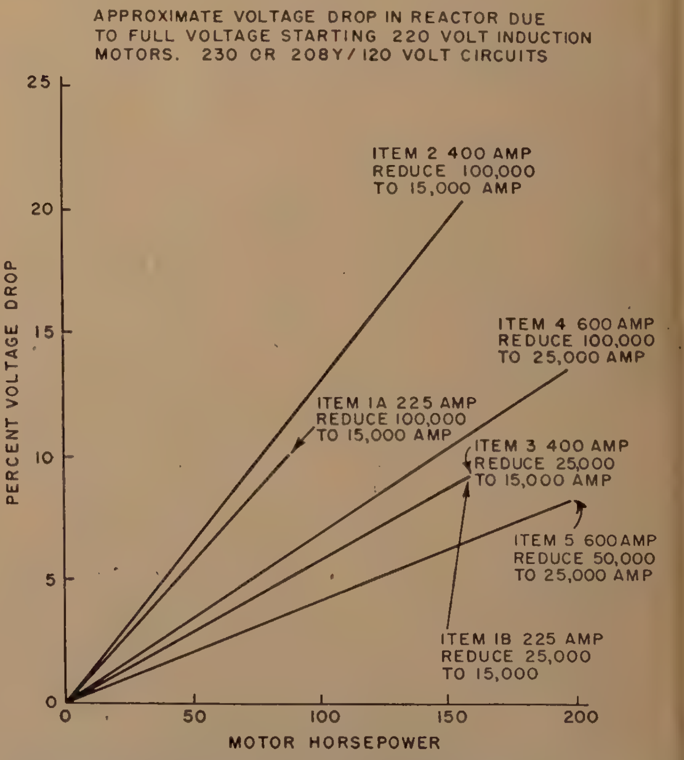


Fig. 13. Voltage dips in full-voltage starting of 220-volt induction motors on 230 or 208Y/120-volt circuits

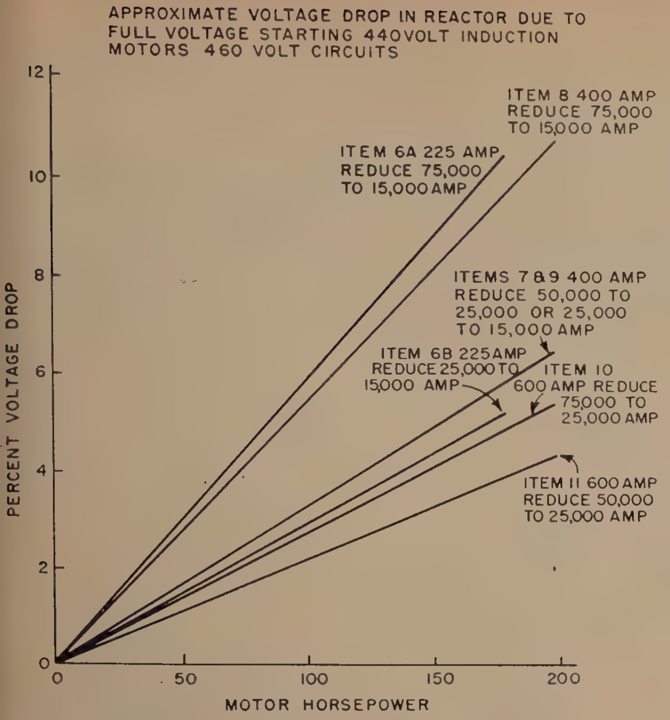
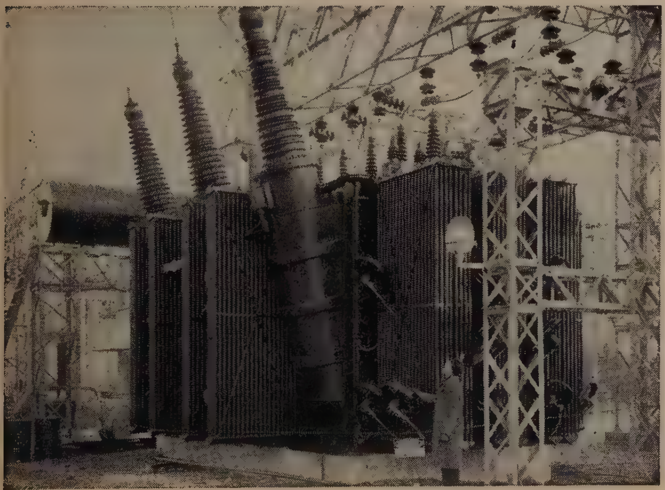


Fig. 14. Voltage dips in full-voltage starting of 440-volt induction motors on 480-volt circuits

208Y/120 volts and 480 volts respectively. Repetitive loads may have a much more serious effect. Thus, the maximum kva of repetitive load allowable without causing flicker may be very low.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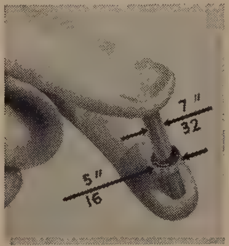

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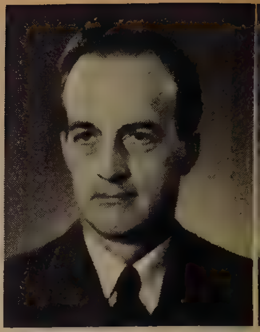

How the basic structures of this switching equipment permit the handling of high voltages. An example of size and weight reduction resulting from fundamental changes in contactor design to meet service requirements

By J. F. McKENNEY
Power Transformer Engineering Division, General Electric Company

James F. McKenney

WHEN the Model-T Ford was in its heyday, it was said that anyone could get any color Ford he wanted—as long as he wanted black. The purchaser was happy to the extent that he could adapt his needs or desires to what the car offered.

In the beginning, load-ratio control for tap-changing under load was in somewhat the same category. Originally, an equipment was developed consisting of a tap-selector switch, a contactor or circuit breaker, and a driving mechanism. This equipment had certain characteristics and, as long as the transformer requirements were within the capabilities of the tap-changing gear, a happy union was possible. Whenever the requirements of the transformer exceeded either the current or voltage rating of the switches, however, artful arrangement of the electrical circuit by means of a series transformer was necessary to adapt transformer requirements to switching capabilities.

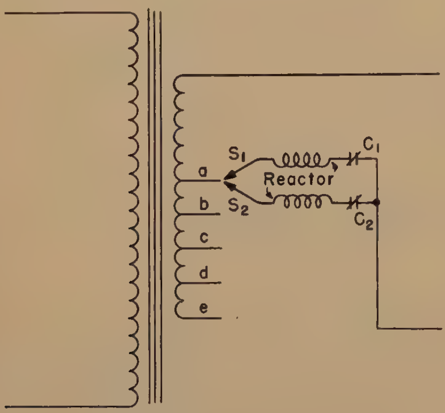

Fig. 1. Basic load-ratio-control circuit

As the art developed and sufficient need arose, new switching equipments were designed to handle higher currents and voltages.

To understand the influence of the switching requirements on the design of the switching equipment, it is necessary to analyze the basic elements of the switches. This article will be confined to the contactors, or circuit-breaking switches, although it should be understood that similar considerations apply to the tap-selector switches.

BASIC SWITCH STRUCTURES

In the basic load-ratio-control circuit shown in Fig. 1, tap selectors S_1 and S_2 are connected to tap *a*. Contactor C_1 is in series with tap selector S_1, and contactor C_2 is in series with tap selector S_2. The load current will divide equally in the two branches of the reactor circuit. A tap change would consist of opening contactor C_2 and, when the current had ceased to flow in that branch, moving tap selector S_2 to tap *b*. After this, contactor C_2 would close. The next step would be to open C_1, move S_1 to *b*, and close C_1.

A study of this procedure in relation to the circuits in which it takes place reveals that a load-ratio-control contactor could be considered as having three basic structures:

(1). A current-handling structure suitable for carrying the circuit currents; capable, also, of interrupting these currents any time that a tap change is made.

(2). An insulating structure able to withstand the voltages which may be applied to the switch.

(3). A mechanism which will reliably produce the necessary sequence of motions involved in a switching operation.

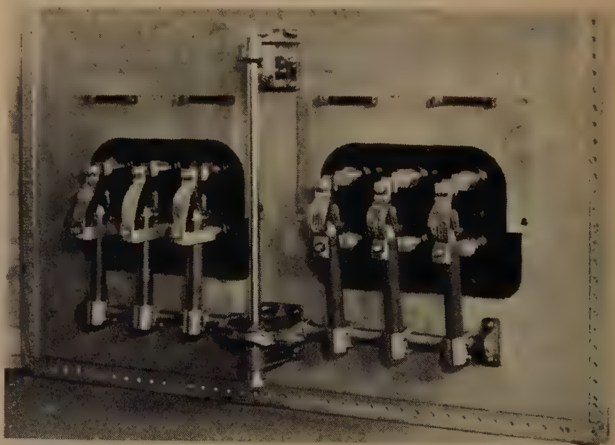

Fig. 2. Basic arrangement for contactors used in circuits from 15 kv to 69 kv

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This article is so paged that, without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—Editor

Although the handling of higher currents will demand larger parts, the high-current switch generally will be arranged in the same pattern as a lower-current switch. It will be shown, however, that fundamental changes in the design of a contactor will be caused by requirements of the insulating structure for higher-voltage circuits.

DESIGN FOR MODERATE CIRCUIT VOLTAGES (15 to 69 kv)

FIG. 2 illustrates the general arrangement which has been found satisfactory for contactors used in circuits from 15 kv to 69 kv. The stationary current-carrying parts are supported by a suitable structure which provides insulation to ground. The mechanism is at ground potential; it actuates the movable current-carrying parts by means of insulating connecting members. As shown in the illustration, the three basic structures are proportioned in good balance, and the arrangement is well adapted to moderate voltage classes.

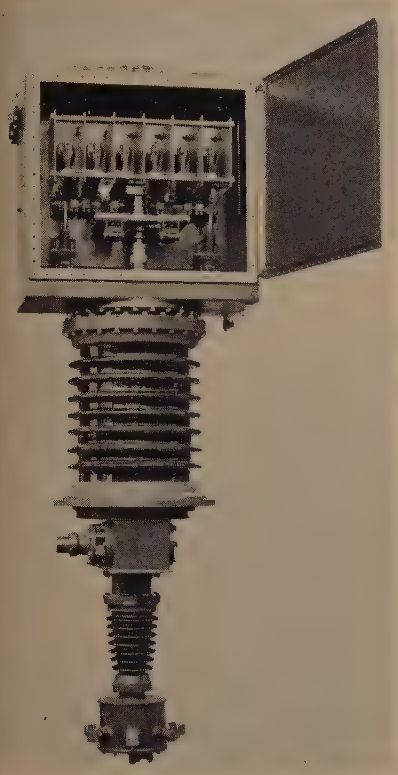

Fig. 3. Basic structures for higher circuit voltages of 92 kv and above, rearranged to meet equipment requirements

DESIGN FOR HIGHER VOLTAGES (92 kv and above)

If the arrangement shown in FIG. 2 were expanded to be appropriate for higher voltages, it would be found that the contactor and its enclosing box would become very large because of the necessarily greater electrical clearances. Therefore, a reconsideration of the three basic structures may disclose a better arrangement.

If the contactor mechanism and box are placed at the electrical potential of the transformer winding tap, such as *a*, *b*, *c*, etc. in FIG. 1, tap voltage will be the only voltage appearing in the contactor box when the contactor is in the open position. Because the insulation required for tap voltage is only a small precentage of that required for circuit voltages of 92 kv and above, a great reduction is possible in the size of the contactor and its enclosing box. Insulation to ground must now be supplied by another structure.

FIG. 3 shows how this may be accomplished. The bushing-like structure, on top of which the contactor box is mounted, provides the insulation to ground. In addition, it serves to bring the electrical connections into the transformer and the insulating mechanical drive shaft up to the contactor mechanism.

Inside the contactor box is mounted the panel-mounted contactor mechanism shown in FIG. 4. Although this contactor has the same current-carrying and interrupting capacity as the one shown in FIG. 2, it is only about one-fifth as large because the insulation to ground is provided elsewhere than on the contactor panel.

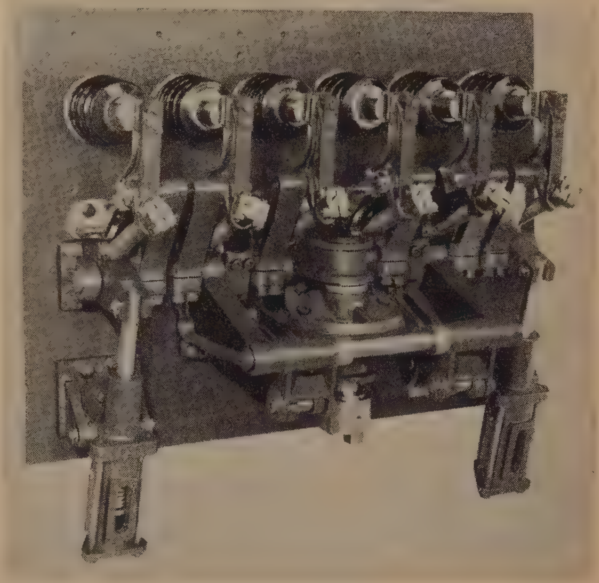

Fig. 4. Contactor panel for the tap changing equipment shown in Fig. 3. Although this panel has the same current-carrying and interrupting ability as the one shown in Fig. 2, it is only about one-fifth as large because only tap voltage insulation is required with this arrangement

BUSHING-MOUNTED CONTACTOR

The contactor shown in FIG. 3 is for the specific application of changing taps in the insulated neutral of a three-phase wye-connected transformer. The contactor is mounted on the transformer cover in the manner of a high-voltage bushing. If it is desired to connect the neutral to a ground-fault neutralizer, connection can be made to a terminal on the contactor box. Because of arcing, the oil in the contactor compartment becomes carbonized and therefore must be kept separated from the oil in the bushing. For this reason the contactor box is divided into two parts: one part serves as expansion space for the oil in the bushing; the other contains the contactor and its separate oil. To maintain the bushing oil at high dielectric strength,

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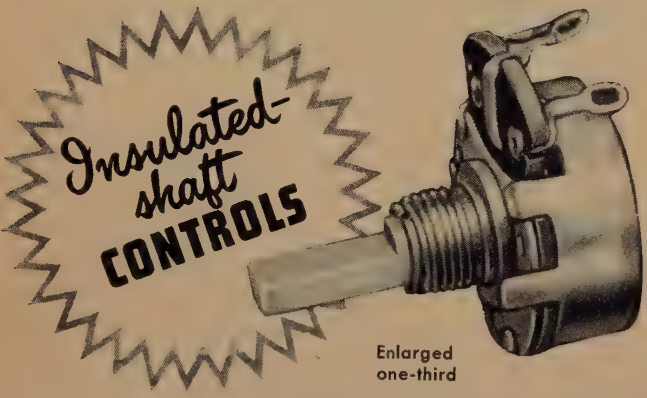

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HIGH-VOLTAGE CONTACTORS

(Continued from preceding page)

it is not permitted to come in contact with outside air; but approximately atmospheric pressure is maintained on the surface of the oil, during expansion and contraction, by means of a U-tube oil seal.

The large porcelain under the contactor box serves only to retain the oil and provide a suitable surface for air insulation. The weight of the contactor is carried by a resin-bonded paper cylinder concentric with, and inside, the porcelain. Differences in thermal expansion between the porcelain and the paper cylinder are permitted by a bellows element at the top end of the porcelain.

A hinged and gasketed door over the front of the contactor compartment facilitates inspection.

The entire unit is completely self-contained.

OTHER VARIATIONS

The three-phase bushing-mounted contactor is suitable only for use in the neutral of a wye-connected transformer. However, single-phase contactors can be built as shown in Fig. 5. In some instances the line lead can be connected to a terminal on the contactor box, thereby eliminating the need for a separate high-voltage bushing.

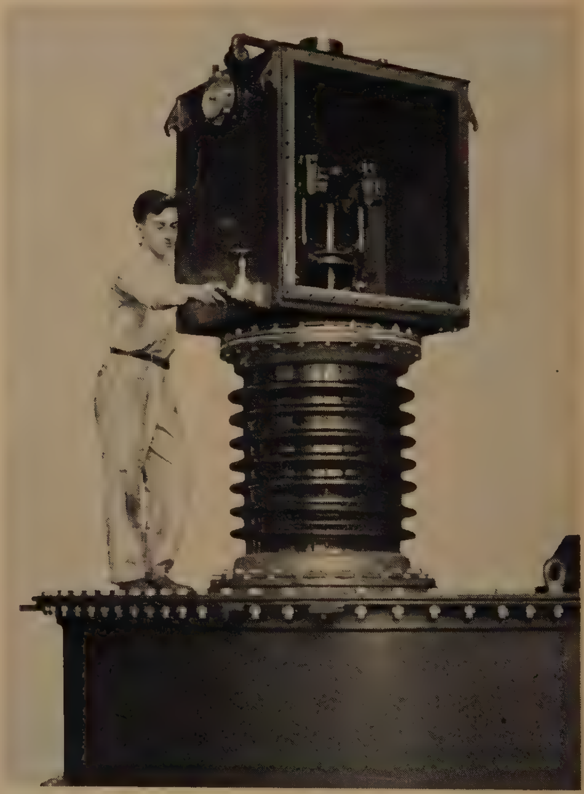

Fig. 5. For certain equipment requirements, single-phase contactors such as this can be used

Bushing-mounted contactors represent an extension in the design of the original switching equipment to make it directly adaptable to transformer needs. Wherever such contactors can be used to advantage, they eliminate the need for that flexible link—the series transformer—thus reducing the size and weight of the transformer equipment.

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SYMMETRICAL, MAXIMUM STRENGTH CASING—because the unit-type rotor assembly eliminates the need for a casing with intricate, cast volute passages.

LOWER PARTS INVENTORY—because maximum interchangeability of rotor-assembly parts makes it unnecessary to stock replacement units for each individual stage.

FLEXIBILITY OF OPERATION to meet changing load conditions—because pump characteristics can be altered by installing a new combination of rotor-assembly units.

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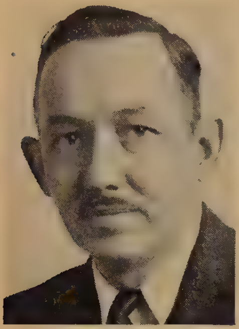
SPOTTING EQUIPMENT FOR SYNCHRONOUS MOTORS



S.C. Ewing

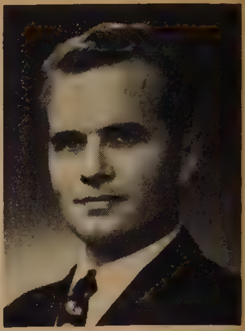
Accurate angular positioning of heavy rotors is accomplished by simple control sequence that gives slow rotation in either direction

By S. C. EWING and E. A. E. RICH

Industry Control Engineering Division

Industrial Engineering Division

General Electric Company



E. A. E. Rich

THE word "spotting" as used in this article refers to the operation of accurately stopping rotating machines in a predetermined angular position. In the broader sense, "spotting" may be either approximate or accurate, and may follow continuous or jogging rotation.

PROBLEM

Quite often normally constant-speed machines have to be rotated at ultra-low speeds, of approximately 1 percent or less of normal rpm, to facilitate visual inspection, threading-in, setting-up operations, etc. In addition, it may be desired to stop the rotation accurately at a fixed angular position. To do this usually means that very slow continuous or jogging rotation must precede the accurate positioning, or spotting, of the drive when stopping. For example, reciprocating compressors and diesel engines have to be accurately positioned to adjust timing of valves. This operation is ordinarily called "barring" whether hand or machine powered and is really but one of a number of possible methods of spotting. Also, as another example, tube mills and rolling mills may require fixed angular positions to load, unload, lubricate, make repairs or adjustments, replace or change parts, etc.

The equipment that is used to obtain ultra-slow rotation and/or spotting varies widely depending on the type of equipment to be slowly rotated and spotted, the frequency, accuracy, and relative difficulty of doing the job, and the cost of the extra equipment needed.

Electric-motor-driven equipments which may require ultra-slow rotation and/or spotting fall into two general classes:

(1). Those which are suitable for operation for the required periods of time—usually short—at very low speeds, as well as at normal speeds. Motors which can be jogged and adjustable-voltage d-c drives may be examples of this type.

(2). Those which are not by themselves very suitable for operation at ultra-low speeds. Synchronous motors, most induction motors, and constant-potential d-c motors are usually of this type.

In many plants, machine operators use line circuit breakers, or contactors, to jog the synchronous or induction motor in spotting the drives. For speedy success, this method requires considerable skill and practice on the part of the operator. Without such skill it may be questionable practice, since the positioning accuracy is very poor and much jogging quickly overheats the motor windings, especially the amortisseur winding. Also, circuit breaker tip life is greatly reduced by jogging. In fact, rapid jogging, using oil contactors or circuit breakers, may result in flashovers due to the rapid carbonization of the oil and accumulation of gas within the breaker.

PURPOSE

The purpose of this article is to describe two applications of spotting equipments for large synchronous motors. These equipments use low-voltage constant-potential d-c power which is mechanically commutated by magnetic contactors in such a way as to produce, in effect, an ultra-low frequency of about ¼ to ¾ of 1 percent of normal frequency. This ultra-low-frequency power, when applied to the a-c motor stator (with the motor d-c field already energized from its normal excitation source) causes the motor to deliver suitable rotational torque at a low average speed at the motor shaft.

This very low frequency in the motor stator windings is obtained by applying direct currents to the three phases of the armature with the connections initially made for two phases paralleled and in series with the third phase. Then, in one phase at a time, the direct currents are successively reversed in the phase sequence ABC, ABC, etc. (or in the reverse sequence if opposite direction of rotation is required). This results in stator flux waves, or poles, which travel slowly around the stator gap surface. FIG. 1 shows a three-phase winding connected to a d-c source in such a way as to make possible flow of direct current through any phase in either direction.

The first and largest-horsepower motor rating to which this type of spotting equipment has been applied by the General Electric Company was installed for the 4000-hp 78.3-rpm 6600-volt 3-phase 60-cycle, 92-pole synchronous steel-mill motor shown in FIG. 2.

This article is so paged that, without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—EDITOR

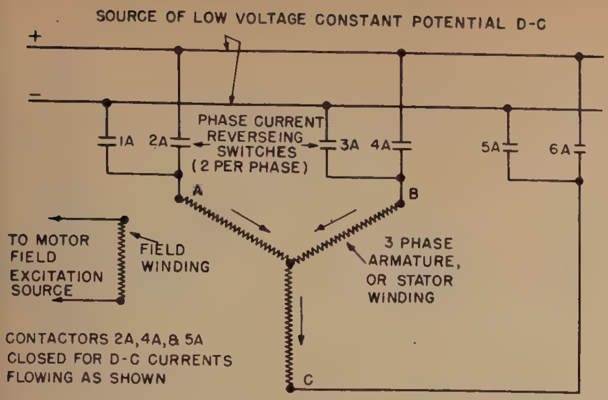

SOURCE OF LOW VOLTAGE CONSTANT POTENTIAL D-C
+
−
1A
2A
PHASE CURRENT REVERSEING SWITCHES (2 PER PHASE)
3A
4A
5A
6A
A
B
C
TO MOTOR FIELD EXCITATION SOURCE
FIELD WINDING
3 PHASE ARMATURE, OR STATOR WINDING
CONTACTORS 2A,4A,& 5A CLOSED FOR D-C CURRENTS FLOWING AS SHOWN

Fig. 1. Diagram of a typical three-phase Y-connected synchronous motor, so connected to d-c source as to obtain current flow in either direction in each phase, depending on which switches are closed

The second application was for a 600-hp 180-rpm 2300-volt 3-phase 60-cycle 40-pole synchronous motor driving a ball mill. Table I lists the performance data of these spotting equipments.

Applications

Spotting equipment is applicable to any synchronous-motor drive (or to wound-rotor induction-motor drives with additional control and d-c power-generating equipment) where, for short periods of time—unless forced-ventilated—ultra-slow rotation and/or accurate positioning or stopping of the driven machine in a given angular position is desired. Thus, drives which use separate starting-gear motors, with overrunning clutches, or equivalent, to obtain ultra-low speeds may instead use spotting equipment to obtain very slow rotation. Also, drives such as ball or tube mills, which have to have fixed angular positions for making adjustments or repairs or replacing expendable parts, or for loading or unloading, as in batch-operated pulverizers, may find spotting equipment useful.

This brief outline of possible uses of spotting equipment is by no means complete.

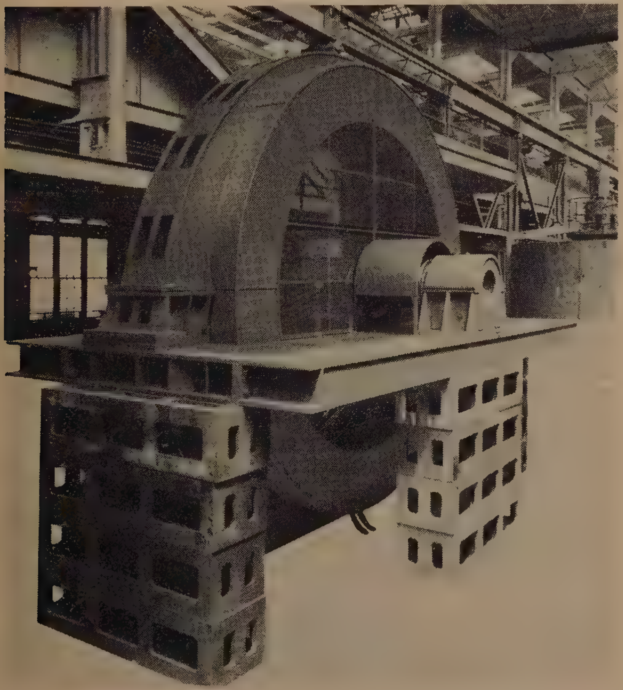


Fig. 2. Shop view of partially assembled 4000-hp 78.3-rpm 6600-volt 92-pole synchronous motor (21½ ft outside diameter) which can be driven at approximately ¼ to ¾ of 1 percent of its normal speed by spotting equipment

TABLE I: MOTOR-SPOTTING DATA

	4000-hp, 78.3 rpm, 6600-v, 60-cycle, 0.8-pf, 92-pole	600-hp, 180-rpm, 2300-v, 60-cycle, 1.0-pf, 40-pole
Percent of rated torque to be spotted	75 percent	120 percent*
D-c required for stator:		
Volts	60	60
Amperes (max)	250	150
Kw	15	9
Rated a-c amperes	345	120
Maximum allowable spotting time without exceeding 25 C additional rise on either stator or rotor windings, rated field current flowing in rotor	8 min	4 min
Minimum time to revolve rotor ½ revolution (based on 0.2 second per step)	55 sec**	24 sec for motor rotor, or 240 sec for mill**

* Since this motor drives a ball mill, it must have sufficient spotting torque to cascade the mill. Cascading torque usually runs about 120 percent of full-speed full-load torque based on the mill using a motor of rating equal to the mill rating.

**4000-hp motor is direct-connected to rolls; 600-hp motor is geared to mill.

It should be noted that for many years construction and service engineering groups have used this basic method during field erection in angular positioning of very heavy rotors of large pump motors and of hydraulic turbine-driven generators, to align coupling bolt holes, etc. The electric equipment used for spotting during the erection of such large machines is usually of a "construction assembled" type. Men are usually used to manipulate the circuits in place of the motor-driven timing switches and contactors. Motor-generator exciter sets, arc-welding generators, etc., are usually used for supplying low-voltage high-current d-c to the armature windings.

DESCRIPTION OF SPOTTING METHOD

The idea of this method is to produce magnetic fields by direct currents flowing through both the motor field and armature circuits; then by changing connections and directions of these direct currents in the armature phase circuits in the proper sequence, to cause the resultant stator magnetic field to slowly move—by small steps—around the periphery of the stator gap surface. The rotor magnetic field interacts with the stator magnetic field in the usual way and tends to follow the stator field as it moves around the gap surface, assuming that the load torque permits.

Physically, this may be visualized by remembering that, in usual operation, a synchronous motor operates as a result of the interaction of stator and rotor magnetic fields which tend to cause the rotor and stator flux-wave centerlines to coincide.

Actually for spotting purposes, it makes little difference just what produces the stator magnetic field. Therefore, by applying direct current to the stator winding as shown in FIG. 3(a), a magnetic field in the stator will be set up which will either tend to attract or repel the motor magnetic field which is already there. If the torque resulting from the fields is strong enough to overcome the friction and load torque, the rotor will move a little until the load torque equals the torque available from the interaction of the two fields. However, the rotor, once it is moving, may have sufficient inertia to continue moving a little beyond the point of equality of load and motor torques.

Then, if phase *A* is de-energized, as shown in FIG. 3(b), the peak strength of the resultant stator magnetic field will be decreased to 86 percent of the peak value in FIG. 3(a). The centerline of the stator magnetic field will now have shifted 30 electrical degrees away from the original position in FIG. 3(a). Thus, the rotor magnetic field again tends to move to the new position, causing slight rotation of the rotor.

The next step is to reverse current flow through phase *A* only, as shown in FIG. 3(c). This causes a stator magnetic field similar in shape and size to that in FIG. 3(a), but shifted 30 degrees more away from phase *A*, or a total of 60 electrical degrees from the original position in FIG. 3(a).

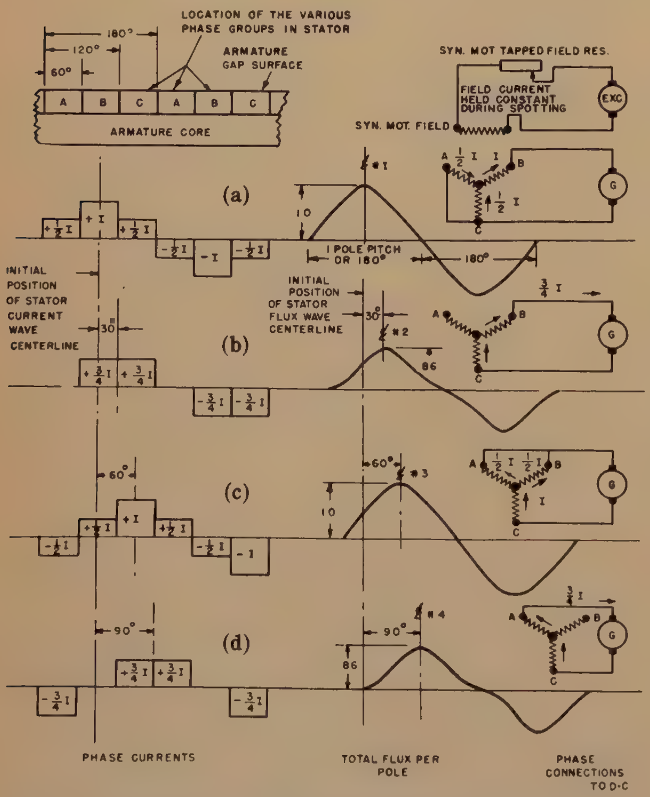

LOCATION OF THE VARIOUS PHASE GROUPS IN STATOR
180°
120°
60°
ARMATURE GAP SURFACE
A
B
C
A
B
C
ARMATURE CORE
SYN. MOT TAPPED FIELD RES.
FIELD CURRENT HELD CONSTANT DURING SPOTTING
EXC
SYN. MOT. FIELD
(a)
(b)
(c)
(d)
INITIAL POSITION OF STATOR CURRENT WAVE CENTERLINE
INITIAL POSITION OF STATOR FLUX WAVE CENTERLINE
1 POLE PITCH OR 180°
180°
1.0
86
30°
60°
90°
#1
#2
#3
#4
G
PHASE CURRENTS
TOTAL FLUX PER POLE
PHASE CONNECTIONS TO D-C

Fig. 3. Schematic diagram of locations and magnitudes of stator phase currents and stator flux per pole during first four spotting steps (a), (b), (c), and (d). The remaining eight steps are successively displaced 30 electrical degrees per step, after which cycle repeats

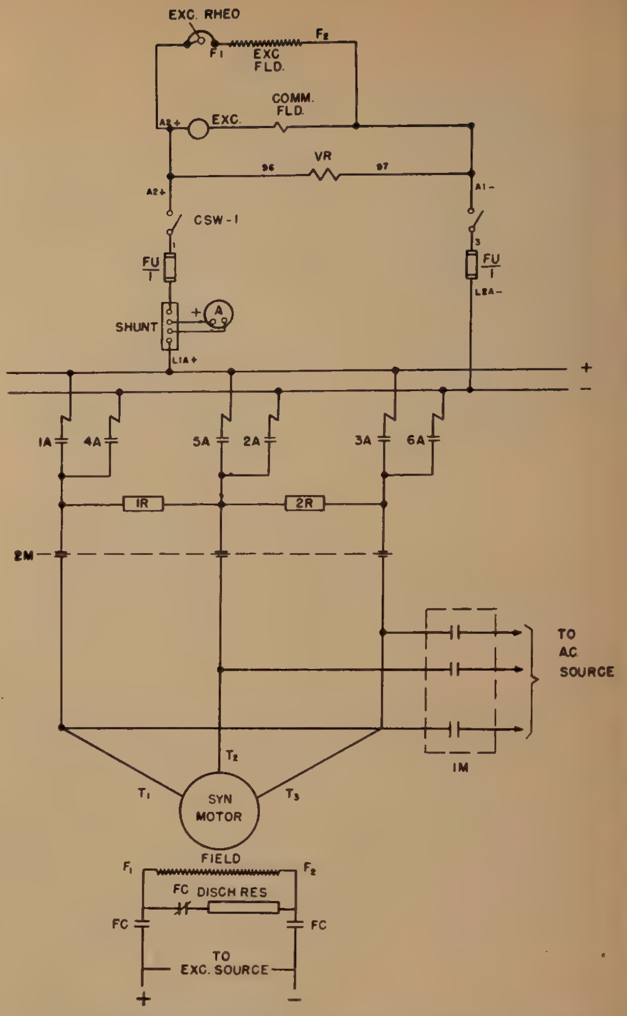


Fig. 4. Power elementary diagram showing connections necessary for spotting a synchronous motor

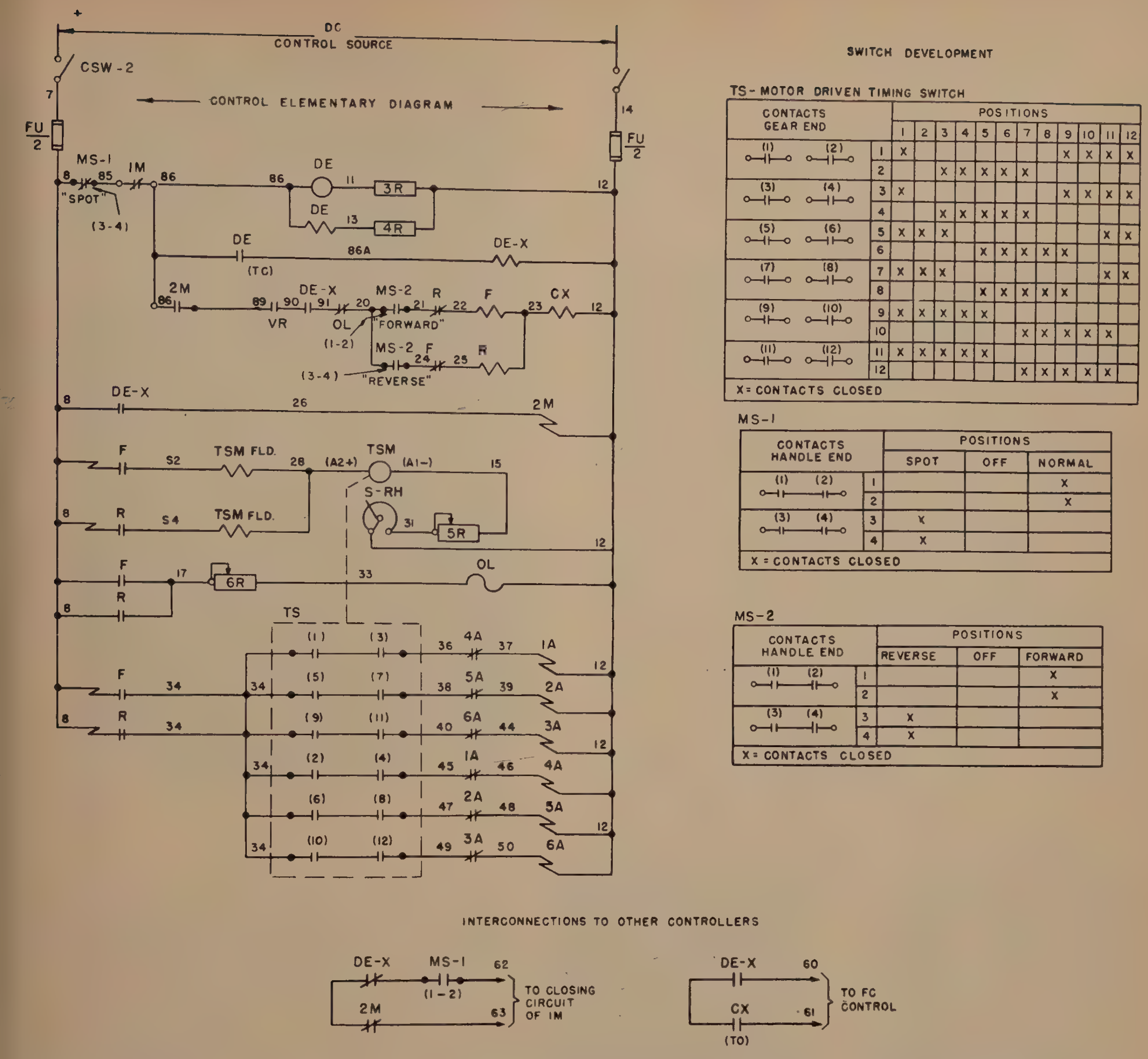
The next step is to de-energize phase *B* as shown in FIG. 3(d), which produces a magnetic field similar to that in FIG. 3(b), but now displaced a total of 90 electrical degrees from the original position.

This process is continued in the sequence shown in FIGS. 4 and 5. It is evident that twelve steps of 30 electrical degrees each are required to traverse the physical distance occupied by one pair of poles, after which the cycle repeats. As a practical matter, successive steps do not move the rotor an equal distance due to different resultant field strengths. Steps such as in FIGS. 3(a) and 3(c) would move the rotor about 40 electrical degrees, while the in-between steps such as in FIGS. 3(b) and 3(d) would move the rotor about 20 electrical degrees, assuming a load torque of about 100 percent.

The peak torque developed, with rated rotor-field current flowing, is given by the following equation:

$$T_m = \frac{1.34 \times \text{kva}}{\text{hp}} \times E_d \times \frac{I_a}{\sqrt{2}} \qquad (1)$$

where T_m = Peak torque in per unit for the connection of two phases paralleled and in series with the third phase, as in FIGS. 3(a) and 3(c).



SWITCH DEVELOPMENT

TS-MOTOR DRIVEN TIMING SWITCH

CONTACTS GEAR END		POSITIONS 1	2	3	4	5	6	7	8	9	10	11	12
(1) (2)	1	X								X	X	X	X
	2			X	X	X	X	X					
(3) (4)	3	X								X	X	X	X
	4			X	X	X	X	X					
(5) (6)	5	X	X	X								X	X
	6					X	X	X	X	X			
(7) (8)	7	X	X	X								X	X
	8					X	X	X	X	X			
(9) (10)	9	X	X	X	X	X							
	10							X	X	X	X	X	
(11) (12)	11	X	X	X	X	X							
	12							X	X	X	X	X	

X = CONTACTS CLOSED

MS-1

CONTACTS HANDLE END		POSITIONS SPOT	OFF	NORMAL
(1) (2)	1			X
	2			X
(3) (4)	3	X		
	4	X		

X = CONTACTS CLOSED

MS-2

CONTACTS HANDLE END		POSITIONS REVERSE	OFF	FORWARD
(1) (2)	1			X
	2			X
(3) (4)	3	X		
	4	X		

X = CONTACTS CLOSED

Fig. 5. Control elementary diagram with switch development and interconnections to main motor controller for synchronous motor spotting

kva = Rated kva of motor

hp = Rated hp of motor

E_d = Direct axis voltage corresponding to field excitation

$$=\frac{\text{Full-load ampere-turns}-\text{saturation ampere-turns}}{\text{Air gap ampere-turns at rated open-circuit voltage}}$$

$=1.4$ to 2.2 roughly (actual value depends on design of particular machine)

I_a = The d-c armature current in per unit (rated a-c amperes = 1.0 per unit)

From Equation (1), assuming a value of $E_d=1.6$ and rated direct current in both rotor and stator windings, $T_m=1.22$ for a typical 1.0-pf synchronous motor. The peak torque is decreased to 86 percent of this value for the armature connection of two phases only in series, or 105 percent peak torque and 75 percent current. Since the torque values calculated so far are peak values only, the actual load torque which can be handled is less than either peak torque just calculated. A good

NOMENCLATURE FOR CIRCUIT DIAGRAMS IN FIGS. 4 AND 5

A:	Ammeter
CSW-1, *CSW-2:*	Knife switches
CX:	Common control relay for *F* and *R*
DE:	Decelerating time relay
DE-X:	Control relay for DE
F:	Forward control relay
FC:	Field contactor on synchronous motor controller
FU:	Fuse
MS-1:	NORMAL-OFF-SPOT selector switch
MS-2:	FORWARD-OFF-REVERSE direction of rotation selector switch
OL:	Overload relay (hand reset) to control maximum allowable spotting time
R:	Reverse control relay
S-RH:	Speed-adjusting rheostat for *TSM*
TC:	Time closing
TO:	Time opening
TS:	Motor-driven timing switch
TSM:	Motor of timing switch
VR:	Exciter voltage relay
1A, 2A, 3A, 4A, 5A, 6A:	Spotting contactors
1M:	Main contactor of synchronous motor controller
2M:	Isolating contactor
1R, 2R, 3R, 4R, 5R, 6R:	Resistors

figure which may be used for actual load torque which may be handled is 75 percent of T_m as calculated by Equation (1), or 90 percent of rated torque for the particular example used here. This is the sort of calculation usually best done by the motor designer since almost all the needed data are available to him.

CONTROL

The necessary control consists of six switching devices (magnetic contactors or electronic tubes) to effect reversal of d-c currents applied to each of the three phases, plus a motor-driven timing cam switch to apply d-c in proper sequence to the three motor phases. The timing-cam switch is driven by an adjustable-speed reversible fractional-horsepower motor. Also required is a protective device to prevent the operator from becoming so entranced with the sequence of contactors busily closing and opening that he keeps spotting long enough to damage motor windings by overheating. In addition, discharge resistors are usually needed to prevent the inductive armature circuits and control circuits from being "hipotted" upon interruption of the d-c armature current during spotting. In addition, some isolating means is required to keep spotting control equipment completely and positively isolated from the main a-c power supply.

Some years ago tests were made on spotting equipment in which a-c power was rectified, using ignitron

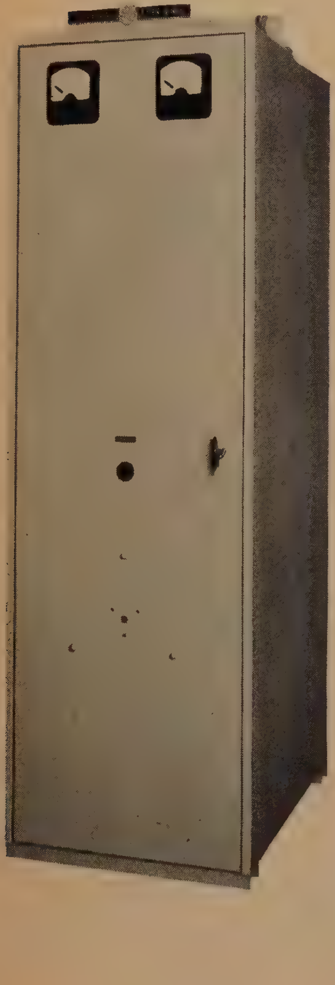


Fig. 6. (*far left*) Magnetic controller for spotting 4000-hp 78.3-rpm 6600-volt synchronous motor shown in Fig. 2. Motor-spotting speed-adjusting rheostat is located on front door

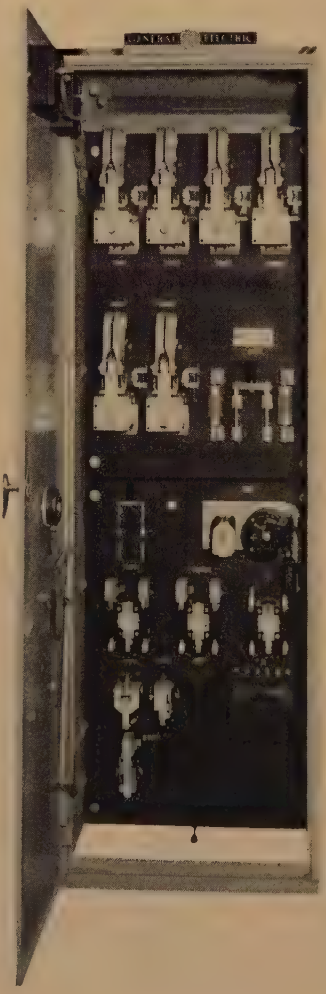


Fig. 7. (*left*) Motor-spotting controller (with front door open) for 4000-hp synchronous motor. The motor-driven timing switch is shown at the top of the lower panel. Isolating circuit breaker is separately mounted in adjoining switchgear

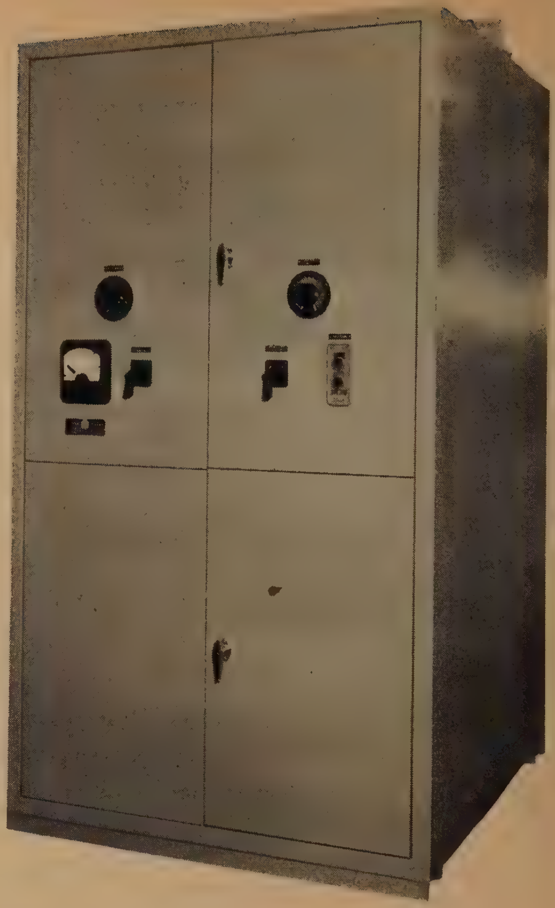
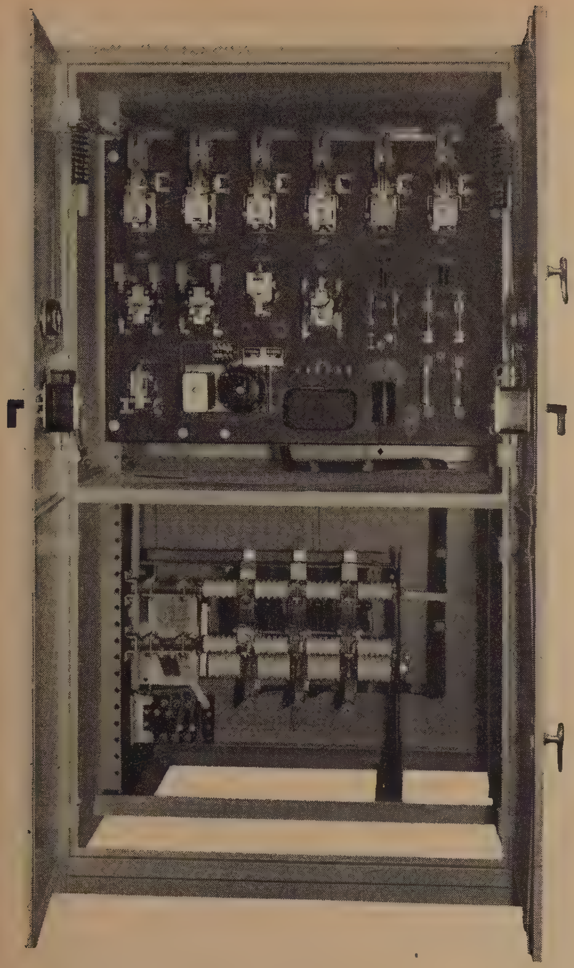


Fig. 8. (*above*) Spotting controller for 600-hp 180-rpm 2300-volt synchronous motor driving a ball mill. Spotting power motor-generator set control is mounted on door, in addition to switches to control direction of spotting rotation and to select "normal" or "spotting" operation

Fig. 9. (*above, right*) Spotting controller (Fig. 8) shown with front doors open. Isolating contactor is in lower compartment and motor-driven timing switch in lower left center of upper compartment



power tubes with phase-shift control to supply suitable d-c spotting power. Directions and sequences of d-c power flow to the main motor stator were controlled by means of a motor-driven timing switch. This method eliminates the rotating d-c spotting power source and six magnetic contactors otherwise needed with a constant-potential d-c power supply. For some ratings, water for cooling of the tubes is required, and in addition, it may cost more than the magnetic control scheme described.

Figs. 4 and 5 show, in an elementary way, the spotting control circuits, using magnetic contactors for switching the low-voltage constant potential d-c spotting power to the motor. The equipment is shown in Figs. 6 to 9.

The isolating means (*2M* in Fig. 4) may be troublesome, hazardous with regard to safety requirements, and costly if certain manual group-operated, double-throw, triple-pole disconnecting switches are used. A separate electrically operated air circuit breaker was used for the 4000-hp mill motor mentioned in this article. Air-break, electrically interlocked, standard high-voltage isolating contactors were used on the 600-hp ball mill motor that was mentioned. These contactors are the same as those employed for mine-hoist, rubber-mill, and other heavy-duty applications.

In addition, a separate source of low-voltage d-c for the stator power during spotting is required. Special low-voltage exciters or arc-welding generators will usually do the job, although for low-voltage synchronous motors rather high currents at quite low voltages are needed, for which suitable d-c generating equipment may not be readily available. For some motors it may be possible to use available d-c shop power with series resistors in place of a separate spotting d-c power source.

DETAILED DESCRIPTION OF CONTROL

With reference to Figs. 4 and 5, the functional sequence for a typical control circuit is as follows:

The main contactor *1M* of the synchronous motor controller must be open, removing a-c power from the motor. When the spotting control switch *MS-1* is transferred to the Spot position, contact (*3-4*) (*8-85*) of *MS-1* is closed and energizes the decelerating time relay *DE*. After a time delay (to insure the synchronous motor is at standstill before spotting equipment can be connected to the stator winding), relay *DE-X* is energized to close the isolating contactor *2M*.

Assuming the exciter has normal voltage available, as indicated by voltage relay *VR*, the control is now set up so that control switch *MS-2* can be operated to start the motor-driven *TS* switch in either the forward or reverse direction. The speed of operation of time switch *TS* is preset by rheostat *S-RH*. The contacts of *TS* switch then close and open in sequence to operate switching contactors *1A*, *2A*, etc., in the sequence shown in Fig. 4 and the switch development diagram for *TS*. When switch *MS-2* is operated, relay *CX* is energized for either position of control switch *MS-2* and sets up a circuit in series with *DE-X* to energize (terminals *60-61*) the synchronous motor field contactor *FC*. Relay *CX* provides time-delay opening so as to maintain field on the synchronous motor for approximately six seconds after *MS-2* is returned to the Off position. This prevents control switch *MS-2* interrupting the synchronous motor field current during very short time intervals when spotting may not actually be going on.

Note that interlocking is provided between *1M* and *2M* and also between the closing circuit to *1M* and position of control switch *MS-1* from Off to Normal or Spot position of *MS-1*.

To prevent undue heating of the motor stator or rotor windings for this spotting operation, a thermal (time-limit) relay *OL* is employed to cause shutdown. This relay is hand-reset.

Control switch *MS-1* is of maintaining type for either position. Control switch *MS-2* is spring return or momentary type.

MODIFICATIONS

Relays *OL*, *DE*, and/or *DE-X* have as their primary functions the protection of equipment and personnel. Other means of performing the same functions could be used, in which case relays *OL* and *DE* might be omitted. In any event, the omission of the functions performed by these relays is a departure from good

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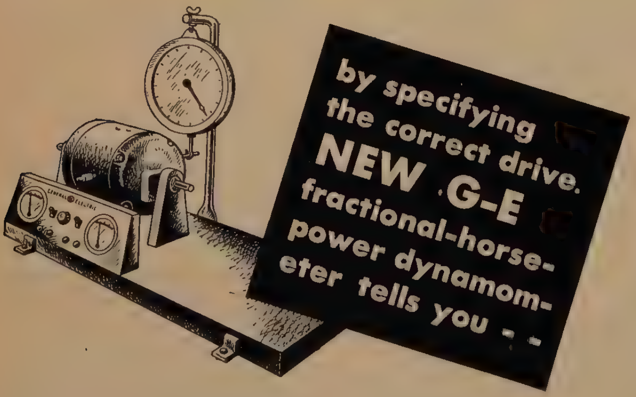

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SPOTTING EQUIPMENT FOR SYNCHRONOUS MOTORS

(Continued from preceding page)

practice, especially for machines of the size and voltage described in this article.

Other possible modifications of the control are:

(a). A small saving could also be made at the expense of ease of adjustment and checking circuits by omitting voltage relay *VR* and d-c ammeter *A* and its shunt.

(b). By increasing the size and complexity of *MS-2*, it could be made to also perform the functions of forward and reverse control relays *F* and *R*, thus eliminating them. This would sacrifice tip life of certain *MS-2* contacts controlling *TSM* field currents since these circuits are highly inductive.

(c). When one spotting equipment is used to spot several motors (one at a time), the various circuits should be carefully interlocked to assure reasonable safety to personnel and equipment. This may introduce considerable complication in control.

The foregoing devices are not strictly essential to perform the basic functions of spotting. They do, however, provide essential protection to equipment and personnel; they make adjustment and checking of operation of spotting equipment easier and quicker; and they help to keep certain components reasonably long lived.

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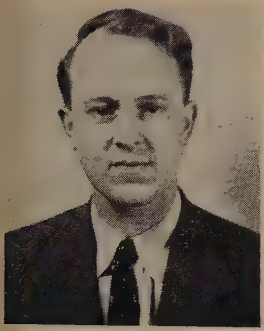


W. D. Williams

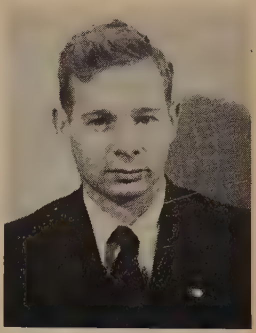
New electronic power supply for producing desired wave shapes of voltage, to provide data on electrical and magnetic phenomena associated with nonsinusoidal excitations

By W. D. WILLIAMS and R. D. ROBINSON

General Engineering and
Consulting Laboratory

Creative Engineering
Program

General Electric Company



R. D. Robinson

THE effect of nonsinusoidal electrical wave shapes on the performance and operation of electrical equipment is being given careful consideration by design engineers today. The demands for faster response and greater reliability in electrical devices have given rise to investigations of performance under all excitation conditions of the operation cycle. In the design of regulating systems, for example, the step function, or steep-front wave, is used as an input signal for stability measurements. A servomechanism which may function properly under steady-state sinusoidal conditions may go into a state of oscillation when subjected to a so-called "shock" wave; hence, a complete operation analysis must of necessity include nonsinusoidal signal inputs.

Indeed, any electrical device which is subjected to a nonsinusoidal wave shape during some period of its operation cycle is in a state in which performance formulas based on the sine wave are invalid. It is here that the engineer must discard his vector-analysis techniques for a more fundamental approach, an approach which generally involves expressions of

$$e=L\frac{di}{dt} \text{ and } e=\frac{1}{C}\int i\,dt$$

Unfortunately, an electrical circuit need have only a few networks, or combinations of L, R, and C, before the analysis becomes a mathematician's nightmare, and the only recourse is test data. In this method the response of a device or an electrical system to nonsinusoidal wave shapes is directly observed by applying various input-signal wave shapes.

But laboratories and test benches have not been equipped with a single-unit power supply capable of producing the wide range of wave shapes necessary for making a complete analysis of wave-shape effects. Thus a need has existed for a generator capable of producing recurrent wave shapes whose configuration is controllable, and capable of producing these wave shapes at power levels sufficient to perform laboratory investigation tests.

Such a generator, called the controlled wave shape generator, has now been constructed, and will deliver 100 watts output at any wave-shape voltage. This generator gives the engineer the necessary control of wave shape which enables him to study the response of his equipment under the particular wave shape which the device may encounter in operation, and opens a field of fundamental research in wave-shape effects on electrical parameters. An example of the latter is the application of the generator in core-loss measurements on ferrous materials under nonsinusoidal flux shape excitations.

DESCRIPTION

The basic principle of the controlled wave shape generator utilizes a line source of light directed at a phototube and modulated by an intercepting rotating cam. FIG. 1 shows the optical system, consisting of an incandescent light source, a diffuser for producing uniform illumination, a light slot, and the receiving phototube. To provide nonvarying light, the light source is powered by a high-frequency oscillator. This eliminates the need for a separate d-c excitation.

The wave shape desired is plotted on standard rectangular co-ordinates and then transferred to polar co-ordinate paper. From the latter plot a cam is cut and mounted between two transparent disks. The cam

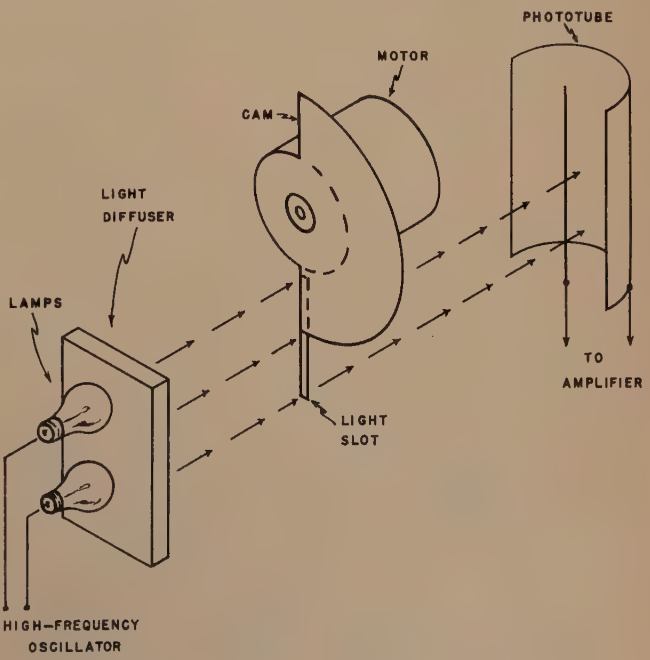


Fig. 1. Optical system for the controlled wave shape generator

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and disks are then rotated by a motor at a speed corresponding to the desired frequency of output wave shape. As the periphery of the cam passes the light slot it modulates the ray, causing the phototube output to assume the wave shape plotted. FIG. 2 shows some typical cam shapes for producing various wave shapes. The linearity of the generator is checked by cutting a triangular wave-shape cam and observing the output shape on a cathode-ray oscilloscope.

The output of the phototube is fed to an amplifier, which converts the signal into usable power. FIG. 3 is the circuit diagram of the generator, which by itself is capable of delivering 10 watts output. This circuit is designed for low-frequency response, since the basic frequency here is in the order of 60 cycles per second.

FIG. 4 is a front view of the generator when combined with a 100-watt amplifier in one panel. The amplifier, designed especially for this application, supplies output from a receptacle in the front. Taps for impedance matching are provided at the back, as shown in FIG. 5.

APPLICATIONS

To demonstrate the versatility of the controlled wave shape generator, as well as to make exploratory studies of possible fields of applications, several tests were made using the generator as an excitation source for different electric and magnetic circuits. These studies are not intended to be complete, but do present sufficient data to indicate the importance of the investigations and to point the way for a more complete analysis in future tests.

MAGNETIC TESTING

As mentioned previously, the controlled wave shape generator provides the necessary power source for core-loss measurements on materials subjected to non-sinusoidal flux shapes. The value of supplying controlled wave shapes to ring samples for magnetic core-loss tests lies in the fact that standard measurement techniques can be applied in measuring these losses. Thus a peculiar wave shape caused by the geometry of a lamination punching can be reproduced in a ring sample of the same material and laboratory methods for measuring losses applied.

For example, the motor designer may wish to evaluate one or more different core materials as a possible substitute for material used in his present machine. His objective here would to be evaluate these new materials on a cost vs. core loss basis, and he would want his core-loss figure to reflect the flux configuration actually existing within the motor. By placing pickup coils at strategic points in the magnetic circuit and integrating the induced voltage, an actual picture of the flux shape can be shown on the cathode-ray oscilloscope. To reproduce this flux shape in a ring sample, a cam for the generator can be constructed from an oscillograph picture of the induced voltage; ring samples of the materials under question can be excited with this voltage shape for loss measurements. From such data the designer is in a better position to evaluate the new materials, since his loss figures represent the same harmonic-containing flux shapes as exist within his machine.

The importance of wave shape on a-c core loss was demonstrated in a test in which a ring sample of motor steel was excited with flat-top sinusoidal wave forms

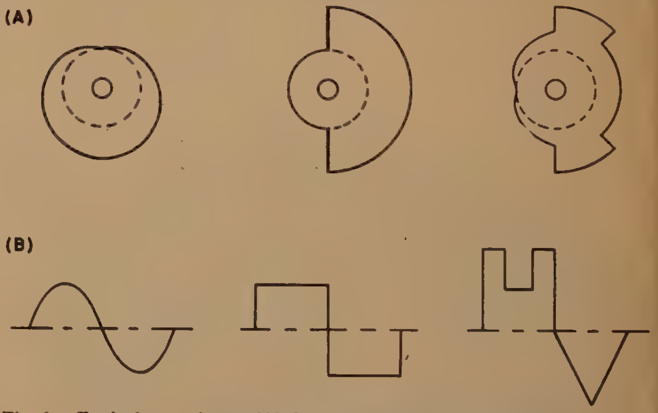


Fig. 2. Typical cam shapes (A) for producing various voltage waves (B)

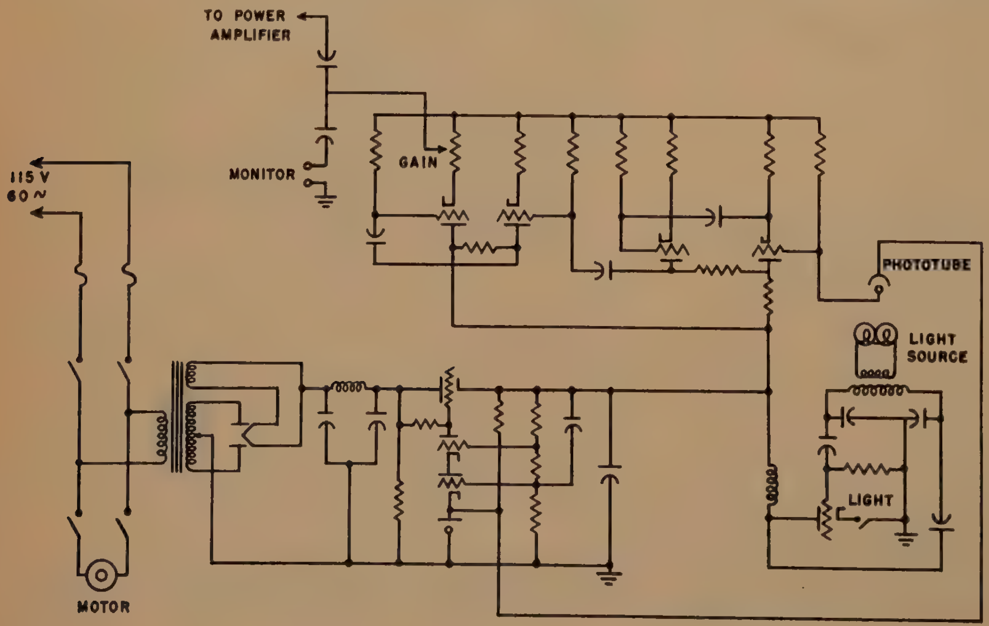


Fig. 3. Circuit diagram for the controlled wave shape generator

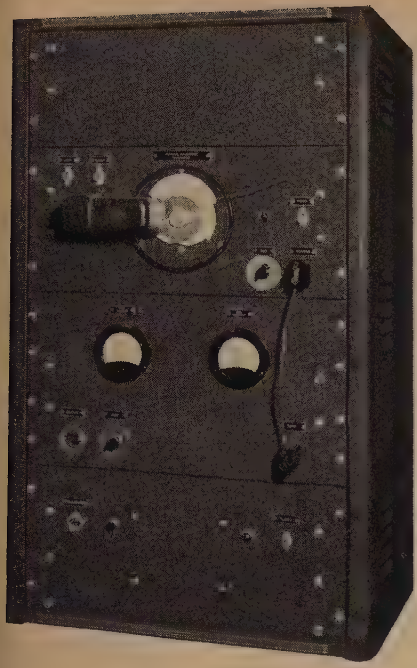


Fig. 4
Controlled wave shape generator with 100-watt amplifier

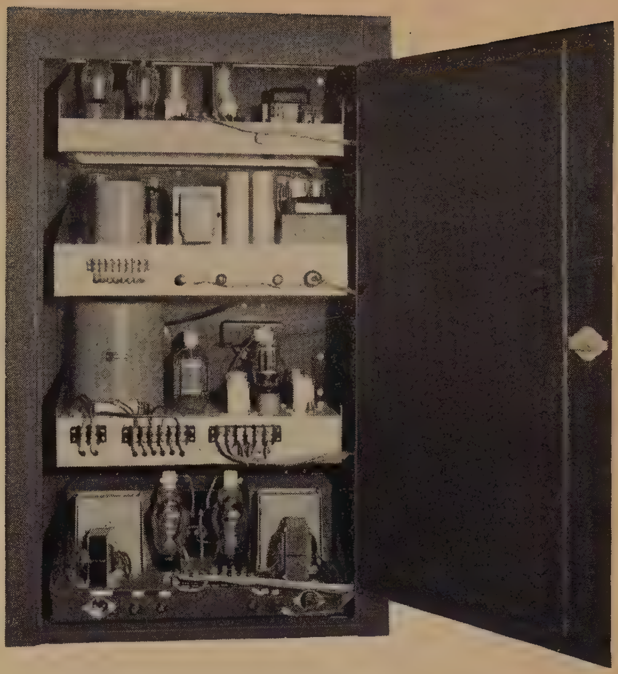


Fig. 5
Rear-door view of the generator

of flux, and the resultant losses compared with an excitation of a pure sine wave as used in standard Epstein specimen core-loss tests. For the same maximum flux density the flat-top flux excitation gave up to 50 percent increase in core loss over the pure sine-wave flux.

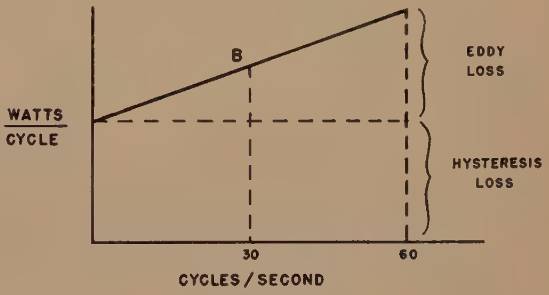
CORE-LOSS SEPARATION

Another application for the generator is in core-loss-separation tests. These tests are made to determine the components of hysteresis and eddy-current losses which make up total core loss. In this country the so-called two-frequency method of loss separation is commonly used. This consists of obtaining a-c core-loss data for a given induction at several frequencies—for example, 60, 50, 40, and 30 cycles per second—then converting them to watts per cycle and plotting them against frequency. Drawing a line through these points gives a zero-axis intercept which represents hysteresis loss in watts per cycle at zero frequency, as shown in Fig. 6. The additional loss at other than zero frequency is the eddy-current loss. The theory behind this method of loss separation is that eddy-current losses per cycle are directly proportional to frequency, whereas the hysteresis loss per cycle is independent of frequency.(1)

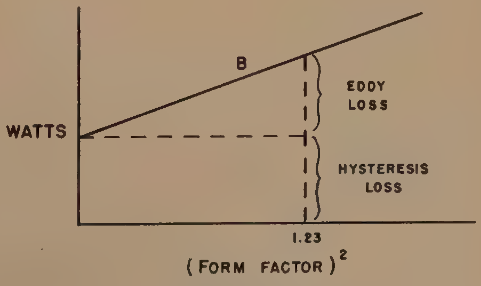
Another method of loss separation is the form-factor method, used to some extent in England. The theory is that if the average induced voltage, and hence maximum induction, is held constant the hysteresis loss remains constant.(2) The difference between any two values of total loss due to different wave forms at the same maximum induction is then the change in eddy loss. Since eddy loss is proportional to the square of the rms voltage, by holding average voltage constant the eddy loss can be expressed as proportional to the square of the form factor. Form factor is defined as rms voltage divided by average voltage. The losses at a given induction and frequency are obtained for several wave forms and plotted on a graph of loss vs. form factor squared. Again the hysteresis component of loss is the zero-axis intercept (Fig. 6).

The controlled wave shape generator is particularly well suited to the form-factor loss-separation method since it can provide the full range of form factors needed for accuracy.

To compare these two loss-separation methods, a ring sample of motor steel was first excited with a pure sine wave at varying frequencies and then subjected to excitations of ten different wave forms at one frequency. Comparing the loss separation by the two methods for



TWO-FREQUENCY METHOD



TWO-FORM METHOD

Fig. 6. Plots of two methods of testing core-loss separation

the same induction and frequency revealed these facts: although the total a-c core loss checked within 1 percent, the loss separation into hysteresis and eddy-current components differed by as much as 10 percent, the two-frequency method assigning a smaller share of the losses to hysteresis effects than the form-factor method. These preliminary investigations show that much is to be learned on form-factor loss separation, and the control of wave shape as afforded by the controlled wave shape generator is essential.

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(1) Numbered references are listed at the end of the article.

In fact, it may well be that the controlled wave shape generator has opened a new field of magnetic core-loss testing. For not only can the effects of nonsinusoidal wave shapes be studied, but also nonsymmetrical cycles can be produced directly by the generator and their effects observed. An interesting investigation would be to see whether losses due to nonsymmetrical cycles can be predicted from a loss vs. form factor curve.

Another versatile feature of the generator is its ability to produce higher frequencies by plotting more than one cycle on the cam. This means that core-loss investigations on nonsinusoidal and nonsymmetrical cycles are not limited to one frequency. Thus the investigator has control of three factors: wave shape, frequency, and power. It is with these controllable factors that major contributions to scientific knowledge of magnetic phenomena can be made.

OTHER APPLICATIONS

Besides the field of magnetic testing, the controlled wave shape generator can be applied to other studies and investigations. For example, it was desired to determine what effect changes in supply wave shape would have on the output characteristics of an amplistat,⁽³⁾ or self-saturating magnetic amplifier. This device operates in a manner similar to a thyratron in that it "fires" each cycle at a conduction angle determined by the input signal. Unlike the thyratron, however, the amplistat has a magnetic circuit through which control is exercised, and it is here that the problems of time constant and gain are encountered. For a given amplistat load and a fixed signal input impedance, a plot of output d-c milliamperes vs. input-signal d-c ampere-turns, as in Fig. 7, will show the range for which linearity in amplification exists. This plot is termed an output characteristic, and Fig. 7 shows the effect of changing the applied wave shape to the magnetic amplifier by means of the controlled wave shape generator. A study of this graph will show that to obtain the greatest linear range a wave shape with a pip, or rise, on the trailing edge will be needed. This is demonstrated by the square wave (pip on right) curve. If a sharp rise from low current is desired a wave shape similar to the box wave can be used.

The results described here were obtained from tests on one particular type of amplistat. Other circuits may indicate different trends. By applying a series of different wave shapes, varying from a triangle and peaked wave to a box and square wave, the response of the magnetic amplifier circuit can be investigated. An analysis of this kind is important not only for supplying performance data for existing wave-shape conditions but also to substantiate operation theories.

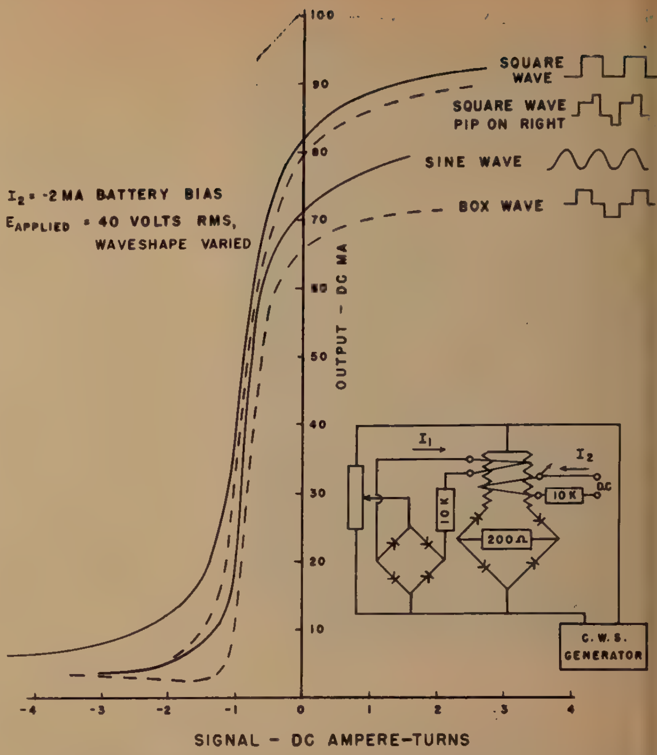


Fig. 7. Amplistat output characteristics, showing effect of wave shape

Other examples of applications for the controlled wave shape generator include investigations of response time of relay equipment and regulating systems under nonsinusoidal wave-shape excitations. Again, meters and instruments can be calibrated for any unusual wave shape found existing in a measuring circuit, so that accurate readings can be taken directly. In each of these applications wave-shape control is accomplished simply and reliably. A permanent record of the wave shape used can be obtained by filing the paper cam along with the test data.

CONCLUSIONS

Wave-shape studies are important in determining the effects of nonsinusoidal excitations on the performance of electric equipment. These studies are facilitated by a new power supply having the unique characteristic of controllable wave shape. As applied to magnetic testing, the generator has provided a new control medium which shows promise of opening a new field of investigations. In other applications this device permits the studies, with a single generator, of wave-shape effects on electrical devices. The operation of this generator is simple, and the cam which determines the wave shape can be stored for future reference.

REFERENCES

(¹)Thomas Spooner: *Properties and Testing of Magnetic Materials*, McGraw-Hill, 1927.

(²)T. F. Wall: *Applied Magnetism*, D. Van Nostrand, 1926.

(³)"The Amplistat and Its Application," by H. M. Ogle, General Electric Review, vol. 53: Pt. I, Feb. 1950, p. 32; Pt. II, Aug. 1950, p. 41; Pt. III, Oct. 1950, p. 41.

HIGH LIGHTS and SIDE LIGHTS

Inert-arc Welding Eliminates Flux Removal Problem

A manufacturer of steel and alloy products for food and chemical industries recently fabricated aluminum salt bins by the inert-arc welding process without flux or special cleaning.

The salt bins have an over-all height of 10 ft 3 in., with diameters ranging from six to eight feet. They are fabricated from aluminum of various gages through ¼ in. No preheat or special cleaning was used, and because of the bulkiness of the bins, many welds were made in the vertical-up and vertical-down positions.

The inert-arc welder eliminated the expensive flux removal problem and nullified corrosive action due to entrapped flux. The inert-arc process is the outcome of fundamental laboratory research.

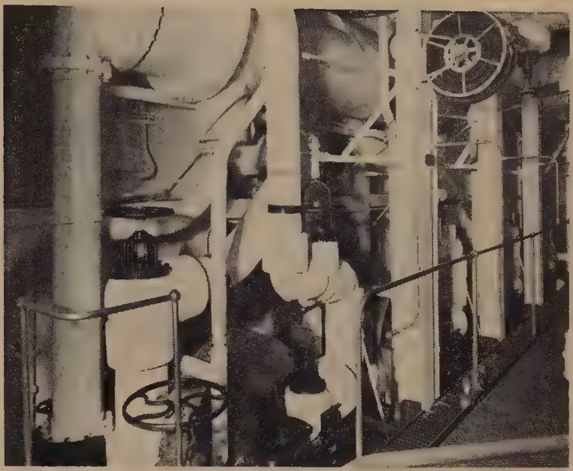
Welding aluminum without flux is one of the applications of the inert-arc process

Pre-warmer for Cold Engines

A new device that will cure the winter ailment of cold motors and hot tempers is the "Calrod engine heater," which gives relief from balky engine starts by prewarming the coolant surrounding the engine block. Only three inches long, it reduces engine wear and starting load on the battery and also speeds warm-up of the car heater. The device is not affected by antifreeze compounds.

The unit is inserted in a small hole cut in the lower radiator hose. Its cord is then plugged into the nearest outlet.

In above-zero weather the heater need be operated only a short while before starting. In sub-zero weather it should be operated for longer periods—even all night if necessary.



DP turbines and gears power four 500-hp cargo pumps

First Marine Installation of DP Turbines

Installation of eight DP mechanical-drive turbines on each of five new tankers marks the first marine use of these standardized turbines. The SS *T. S. Peterson* is the first completed ship of the 28,000-ton tankers.

The turbines are used for three different applications. Four 500-hp single-stage turbines will be used on each ship to power the cargo pumps. The 5000/1750-rpm units operate under steam conditions of 550-psig inlet pressure and 4-psig exhaust. Temperature conditions are 550 F, total temperature.

Three 226-hp 4460-rpm units power the main boiler feed pumps. Inlet pressure is 545 psig, exhaust pressure 20 psig under temperature conditions of 505 F, total temperature.

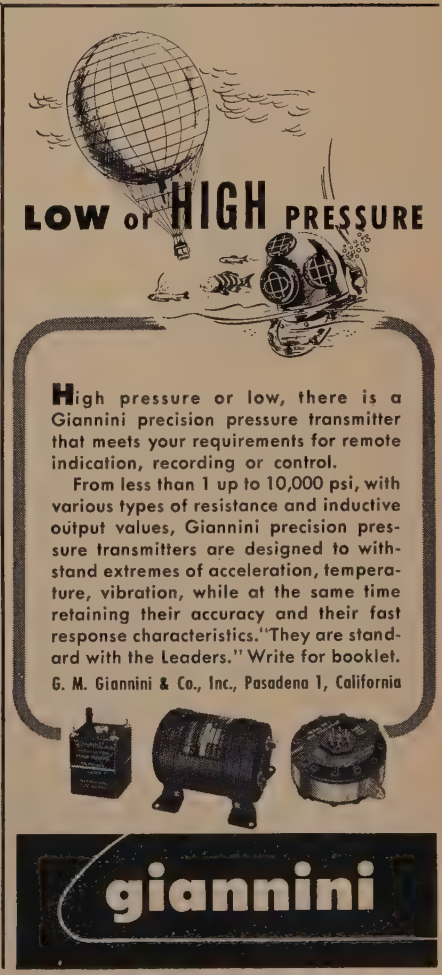
One unit will power the fire pumps and Butterworth system. This 94-hp DP runs at 3000 rpm under identical steam and temperature conditions as the main boiler feed pumps.

Flaw Finding by Shear Waves

A technique for quickly detecting invisible cracks and flaws in high-pressure piping, recently described, employs a particular type of ultrasonics known as shear waves. Because of their lower speed and thus shorter wave length, shear waves are more conducive to detecting small flaws than other ultrasonic waves of the same frequency.

A small "transmitter" placed on the side of the pipe sends the shear waves circularly through the wall of the pipe to an ultrasonic measuring instrument, utilizing an oscilloscope, which records the echo waves in the form of a thin line of light as they leave the pipe. Any deviation in this line of light such as a vertical deflection indicates a flaw in the pipe.

If pipes containing small cracks and flaws were allowed to be used, they might eventually burst. Testing by shear waves is believed the most exact way yet found to assure high quality.



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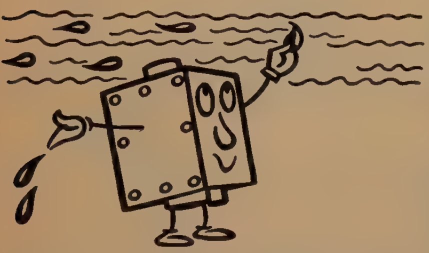
AIR-MAZING FACTS

WHY SMOKERS GET STEAMED UP. If you like to smoke a pipe, you might enjoy a few puffs on your kitchen tea kettle, too. It's been found that about 70% of the so-called "smoke" from a pipe is actually steam.

ELIMINATES DUST ELECTRONICALLY! Electromaze electronic air filters "electrocute" dust, pollen—and even smoke particles. New "file drawer" design makes Electromaze lighter, stronger, easier to service. Users report prefabricated holding frames cut installation costs in half!



SORTS OIL FROM AIR! To keep troublesome oil out of crankcase ventilation systems, most internal combustion engine manufacturers use Air-Maze oil separators. Oil droplets are removed from the air stream, collected, and returned to crankcase. Available to engine builders in open-to-atmosphere types and in-line or closed circuit types.

WHETHER YOU BUILD OR USE engines, compressors, air-conditioning and ventilating equipment, *or any device using air or liquids,* the chances are there is an Air-Maze filter *engineered* to serve you better. Representatives in all principal cities, or write Air-Maze Corporation, Cleveland 5, Ohio.

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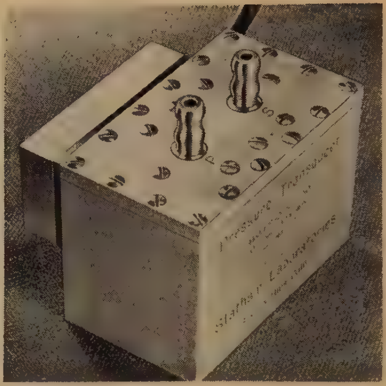
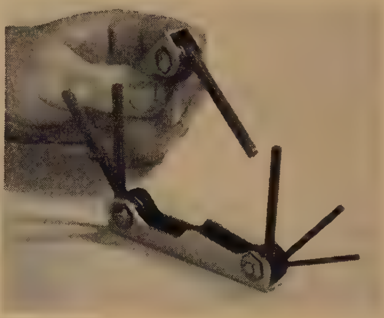
NEW PRODUCTS: AND WHAT THEIR MAKERS HAVE TO SAY ABOUT THEM



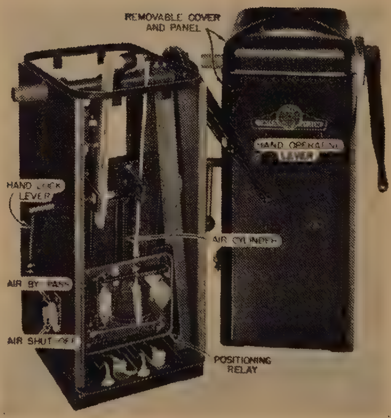
Transducer

Model P69 pressure transducer designe to operate with a wide variety of controlling indicating, recording, and telemetering cir cuits. The balanced construction assure long life and excellent performance unde conditions of vibration and acceleratio such as are encountered in flight-test an guided-missile applications. The transduce is temperature compensated over the range −65 F to 250 F. The unit also can measure either gage or differential pressure in th ranges 0–1 to 0–20 psi, and is offered as a absolute pressure transducer in the range 0–15 psia.—*Statham Laboratories, Inc. 9328 Santa Monica Blvd., Beverly Hills Calif.*



Tool

A hand tool named Smitty containing five of the most popular standard-sized socket-head wrenches that fold knife-like into a single sturdy handle. Small enough to fit conveniently into a pocket, yet designed to permit greater leverage than ordinary wrenches, it offers easy access to even the most difficult places. The individual wrenches, which can be reground when worn, are made of high-quality tempered steel to assure long life. Replacement of the individual wrenches is easily and quickly accomplished.—*H. D. Hunter Co., Los Angeles, California.*



Control Drive

A characterized control drive which can be tuned to the requirements of a special application consists of a double-acting air cylinder, a positioning relay, and a manual operating wheel or lever. This enclosed air-operated drive makes it possible to parallel characteristics of a driven device with characteristics of other equipment and thereby obtain a unified system. Reaction to increased control pressure may be completely reversed by three simple adjustments, and drive travel and loading pressure range can be changed easily and quickly. The drive is suitable for outdoor power plants, cement mills, foundries, fuming plants, pulp and paper mills, chemical plants, and other process plants.—*Bailey Meter Co., 1050 Ivanhoe Rd., Cleveland 10, Ohio.*

Capacitors

A line of vitreous enamel capacitors, 0.68 μμf to 1000 μμf, rated at 500 volts d-c. The units are manufactured by laminating a low-loss ceramic dielectric and metallic silver, then firing the structure to create a monolithic block containing the component The continuous nature of the rigid body imparts unusually stable temperature characteristics to the capacitors, and the materials insure losses equivalent to silve mica at all frequencies. External connections to silver terminals are made wit high-temperature solders, permitting thei use at temperatures from −55 to 200 C —*Vitramon, Inc., Stepney, Conn.*

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Switchboard Instruments

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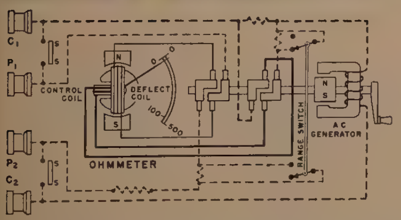
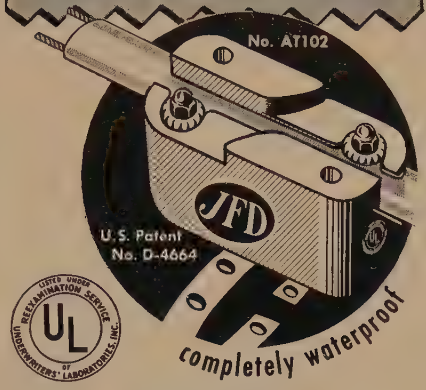
Ground Tester

A CVM type Megger ground tester for neasuring resistance to earth of ground connections. This tester provides a depend-able and easy method for ascertaining whether resistance to earth of man-made grounds is sufficiently low to ensure correct operation and to minimize dangers due to ightning. The set has its own generator or supplying test current and therefore s always ready for service without de-endance on battery or other supply. Two witches are used which short-circuit the erminals for 2-, 3-, and 4-terminal tests. Each instrument has two scales, permitting open well-proportioned markings. Two anges are available: 0 to 40 and 0 to 200 ohms; 0 to 100 and 0 to 500 ohms.—*James G. Biddle Co., 1316 Arch St., Philadelphia Pa.*

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CORE BINDERS—A comprehensive bulletin "Phenolic Resins for Foundries" presents technical data on the fast-baking resin core binder No. G-E 12300. Included are baking curves with complete data on green and baked core properties, suggested core mixes, and suggested mixing and baking instructions. Twelve pages. Bulletin CDC-176.—*Chemical Department, General Electric Company, Pittsfield, Mass.*

ELECTRONIC TUBES—An engineering manual and catalog containing electronic-tube data covering the subject of gaseous discharge rectifier and control-rectifier tubes. Amply illustrated with diagrams, the text includes information on ratings, applications, and life expectancy. The two main divisions present the design of the rectifier unit and the grid-control rectifier unit. Sixty-eight pages.—*Electrons, Inc., 127 Sussex Ave., Newark 4, New Jersey.*

INSTRUMENTS—The 1950 edition data book and catalog containing prices, application suggestions, and pertinent information concerning instrument sensing units and associated accessories. A convenient table of contents lists the main subjects, with the numerous sub-topics appearing beneath each. Included are resistance bulbs and wells, radiation detector, special thermocouples for plastic injection, and extrusion machines, and a new molten-metal thermocouple for ferrous metals. Forty-two pages. Bulletin TC-8.—*Wheelco Instruments Co., 847 W. Harrison St., Chicago 7, Ill.*

MIXERS—Two catalogs presenting engineering data on additions to a line of mixers. Designed for easy reading, the catalogs have large readable type, simple diagrams, and concise tables for quick reference. Titled "Portable Mixers." Twelve pages. Bulletin No. 500. Titled "Fixed Mounting Mixers." Sixteen pages. Bulletin No. 600.—*Eastern Industries, Inc., 296 Elm St., New Haven 6, Conn.*

RESISTANCE TESTER—Contains data on 29 Vibrotest models, including resistance testing ranges and test potentials. The advantages offered for modern insulation testing are listed. Four pages. Bulletin 2A.—*Associated Research, Inc., 3758 W. Belmont Ave., Chicago 18, Illinois.*

STREET-LIGHTING CONTROL EQUIPMENT—A detailed description of street-lighting control equipment for series and multiple circuits. A page each is devoted to data of various components including controllers, protector, dropout cutout, fuse cutouts, photoelectric relay, and remote-control relays. Eight pages. GEC-673.—*Apparatus Department, General Electric Company, Schenectady 5, New York.*

WATTHOUR METER TEST TABLES—Descriptions of test tables designed for fast low-cost meter testing. Includes construction and electrical features, circuit data, rating, and equipment arrangements. Twenty pages. Catalog No. 1—Section 3E.—*States Co., 19 New Park Ave., Hartford 6, Conn.*

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BOOK REVIEWS

(Available books may be purchased through the GENERAL ELECTRIC REVIEW for domestic delivery: none sent on approval.)

THE INTEGRATED POWER SYSTEM

Philip Sporn—McGraw-Hill Book Co., New York. 1950. 157 pp. $4.00.

This book, which can be read completely in one or two evenings, treats in a most concise manner the social and economic objectives, technical requirements, components, tools, personnel, and economic problems of the modern integrated power system. The author, a leader in the power industry, has produced a book unique and dynamic by describing the human, social, and economic objectives as well as the physical and technical means to realize these ends. The book should be read by all executives, engineers, and administrators whose job it is to obtain more economic power systems.

Technical readers could well afford to call this volume to the attention of economists, investigators, and legislators as a means of giving them a comprehensive picture of an industry whose continued progressive development is important to the welfare of our society.

The book is well documented by references and can be used as a guide to more detailed technical papers.

S. B. CRARY

PRIMARY BATTERIES

George Wood Vinal—John Wiley & Sons, New York. 1950. vii+336 pp. $5.00.

In this work the many types of primary batteries are given thorough treatment. The book begins with the earliest efforts to produce electrical energy by chemical means and traces the steps which led to the reliable, low-cost primary batteries we know today. The conventional dry cell is covered in considerable detail from the standpoint of manufacture, tests, and application.

Over fifty pages are devoted to the standard cell, which forms such a vital part of precise laboratory equipment. Both the electrical-measurements specialist and the occasional user of standard cells will benefit much by a careful reading of this material.

The mercuric oxide cells now used in many hearing aids and such special-purpose cells as the caustic soda, silver chloride, and perchloric acid types are given appropriate treatment.

Dr. Vinal's long association with the National Bureau of Standards gave him a unique opportunity to intensively study this field in all its varied aspects.

GEORGE GARDNER

RADIO OPERATOR'S LICENSE Q & A MANUAL

Milton Kaufman—John F. Rider, New York. 1949. 608 pp. $6.00.

Radio Operator's License Questions and Answers Manual is designed for those who have had suitable technical or engineering training, to assist them in passing the examinations for the various grades of radio operator's licenses issued by the Federal Communications Commission, and often required in connection with experimentation and development.

Its greatest use is as a study and reference manual by technicians who are preparing to take FCC examinations, or by those who are engaged in radio-station operation and desire a reference source which is readily understandable.

Well written and up-to-date, the book is a practical encyclopedia covering the operation of FM, television, standard, and other types of broadcast stations, and contains a wealth of up-to-date information of value to the operating technician.

W. J. PURCELL

JOSEPH HENRY: HIS LIFE AND WORK

Thomas Coulson—Princeton University Press, Princeton. 1950. 352 pp. $5.00.

Here is a biography of extraordinary significance to the electrical industry. Joseph Henry, distinguished for his contributions to knowledge of electricity and magnetism specifically by the unit named in his honor is an American scientist not heretofore sufficiently acclaimed. The intermingling of his experiences with those of fellow-scientists, artisans, inventors, and politicians during his early years of experimentation and discovery at the Albany Academy, later as a professor at Princeton, and finally as secretary of the Smithsonian Institution in the full and turbulent period of the Civil War, profoundly influenced American economic history. The magnitude and variety of his work have been often overlooked. This tracing of his career from Albany via Princeton to Washington is a choice contribution to engineering literature. Author and publisher alike have exercised rare talents in producing a book that every thoughtful engineer should read.

J. E. GLICK

KENT'S MECHANICAL ENGINEERS' HANDBOOK (12th Edition)—Two volumes. John Wiley & Sons, New York. 1950. $8.50 each.

Power (1469 pp.)—J. Kenneth Salisbury, Editor.

This edition represents a complete reevaluation of material presented in the prior edition, with the result that some organizational changes have been made, most of the material has been rewritten and brought up to date, and new sections on atomic power and combustion gas turbines have been introduced. The presentation is very good. Basic physical principles and definitions of terms have been carefully explained and sample calculations, illustrations, and graphs generously used. In many cases data are presented on performance typical of modern design, and comparative methods of operation or analysis are discussed. This book should be a particularly useful tool for work in heat-power engineering for the design of systems and specification of system components.

R. V. PRUCHA

Design and Production (1670 pp.)—Colin Carmichael, Editor.

The subjects included here are too broad to more than hint at, but in general the book covers the characteristics of mechanical materials, the design and performance of mechanisms, and the processes used in manufacturing. Included, of course, are such common but important items as the dimensions of standard products, physical properties of metals, etc.

Since each section has been written by a specialist in the particular field covered, the book represents the amassed experience of a large number of sources.

The handbook should be useful to any engineer concerned with the practical aspects of manufacturing and design.

PAUL B. ROBINSON

LIBRARY NOTES

ON ARTICLES IN OTHER TECHNICAL JOURNALS

ACOUSTICS

HIGH-LEVEL NOISE SOURCE FOR THE AUDIO-FREQUENCY BAND. H. D. Harwood and D. E. L. Shorter. *Jour. Sci. Instr.*, Sept. 1950; v. 27, p. 250.

An argon-filled thyratron is used to generate a continuous noise spectrum for audio-frequency testing.

ON THE ACOUSTICS OF COUPLED ROOMS. Cyril M. Harris and Herman Feshbach. *Acoustical Soc. of Am. Jour.*, Sept. 1950; v. 22, p. 572.

Treats coupled rooms as a boundary value problem.

ELECTRON TUBES

DEKATRON; A NEW COLD-CATHODE COUNTING TUBE. R. C. Bacon and J. R. Pollard. *Electronic Engng.*, May 1950; v. 22, p. 173.

Describes with circuit details three types of multielectrode cold-cathode tubes for electronic counting and computing.

DISTRIBUTED POWER AMPLIFIER. A. P. Copson. *Elec. Engng.*, Oct. 1950; v. 69, p. 893.

Describes an improved wide-band amplifier.

FOUNDRY PRACTICE

APPLICATION OF A FLUIDITY TEST MOLD. E. C. Hart. *Foundry*, Oct. 1950; v. 78, p. 100.

Improved controls obtainable in the steel foundry through use of fluidity testing are described.

NEW METHODS PRODUCE PERMANENT MOLDS. G. A. Robinson. *Iron Age*, Sept. 28, 1950; v. 166, p. 82.

Low-cost permanent molds produced accurately and speedily through new methods using sprayed metals.

GAS TURBINES

CONTRIBUTION TO THE DESIGN OF RADIAL-TURBOMACHINES. O. E. Balje. *Tech. Data Digest*, Sept. 1950; v. 15, p. 21.

Considers the problems of computing the efficiency and calculating the characteristics of radial-turbomachines.

GAS-TURBINE ALLOYS, 10 YEARS LATER. Howard Scott. *Metal Prog.*, Oct. 1950; v. 58, p. 503.

Describes the development of high-temperature alloys for gas turbines.

SUPERSONIC COMPRESSOR. Robert McLarren. *Aero Digest*, Oct. 1950; v. 61, p. 50.

Describes the factors involved in increasing the pressure ratio of turbojet engine compressors.

HYDRAULIC TRANSMISSION

DESIGNING HYDRAULIC CYLINDERS FOR HIGH PRESSURES. Woodrow L. Wroble. *Mach.*, Sept. 1950; v. 57, p. 149.

Outline of a method for applying simple formulas and new sealing principles to high-pressure cylinder designs.

SYNTHETIC HYDRAULIC FLUIDS. C. M. Murphy and W. A. Zisman. *Prod. Engng.*, Sept. 1950; v. 21, p. 109.

Possibilities of new types of hydraulic fluids are compared with modified petroleum oils, for aircraft and industrial applications.

LUBRICATION AND LUBRICANTS

BOUNDARY LUBRICATION OF STEEL. William Davey. *Ind. & Engng. Chem.*, Sept. 1950; v. 42, p. 1837.

Boundary lubrication of steel by blends of acids, esters, and soaps in mineral oil has been studied by means of the four-ball machine.

FORGING DIE LUBRICATION. Walter E. Lang. *Metal Prog.*, Sept. 1950; v. 58, p. 337.

A thin water emulsion of colloidal graphite is considered a superior coolant and lubricant for hot-work dies.

MACHINE SHOP PRACTICE

HOW TO LAP. Miles J. Rowan. *Am. Mach.*, Oct. 2, 1950; v. 94, p. 97.

Describes the principles of lapping and the methods by which the operation is performed.

TOOL CONTROL BEGINS AT THE CRIB. Jay DeEulis. *Steel*, Sept. 25, 1950; v. 127, p. 70.

Describes a co-ordinated cutting-tool program to increase efficiency and cut costs.

PUMPS

GOOD WEARING RINGS MAKE GOOD PUMPS. H. E. Tracy. *Power*, Sept. 1950; v. 94, p. 79.

Presents information for proper maintenance of wearing rings on centrifugal pumps.

MODERNIZED TESTING FACILITIES REDUCE THE COST OF PUMPS. Lloyd M. Dings, Jr. *Prod. Engng.*, Sept. 1950; v. 21, p. 85.

A description of a new modernized pump-testing laboratory.

REFRIGERATING ENGINEERING

DISPOSAL REFRIGERANT CONTAINER. E. M. Esberg. *Refrig. Engng.*, Oct. 1950; v. 58, p. 979.

A report of the development of the disposable, pressurized container for refrigerants.

SIZE REFRIGERANT LINES FOR LOW COST. *Power*, Sept. 1950; v. 94, p. 91.

Suggestions for choosing pipe size that will give best economy in your refrigerating plant.

SUBSTATIONS

BASIC SUBSTATION BUS PATTERNS PROVED BY OPERATING RECORD. E. J. Archbold. *Elec. Wld.*, Sept. 25, 1950; v. 134, p. 94.

Georgia Power guides design of substation bus layouts by watching operating record of various schemes.

TRANSMISSION SUBSTATION DESIGN; A DEPARTURE FROM THE USUAL. E. V. Sayles. *Elec. Engng.*, Oct. 1950; v. 69, p. 886.

Describes new design features of substations.

TOOL ENGINEERING

EVALUATING TOOL PERFORMANCE. Thomas Badger. *Tool Engng.*, Sept. 1950; v. 25, p. 17.

Describes a test which accurately predicts shop results for cutting-tool materials.

MAKE TOOL DESIGN MORE EFFECTIVE. N. M. Perris and H. K. Keever. *Steel*, Oct. 2, 1950; v. 127, p. 82.

Treats the evaluation of tool designs before tools are made.

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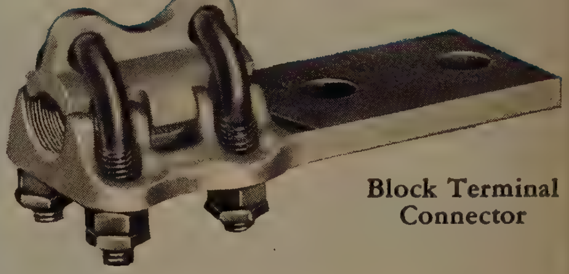
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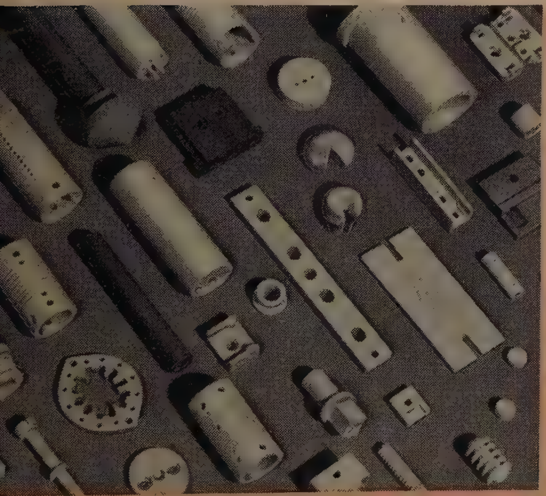

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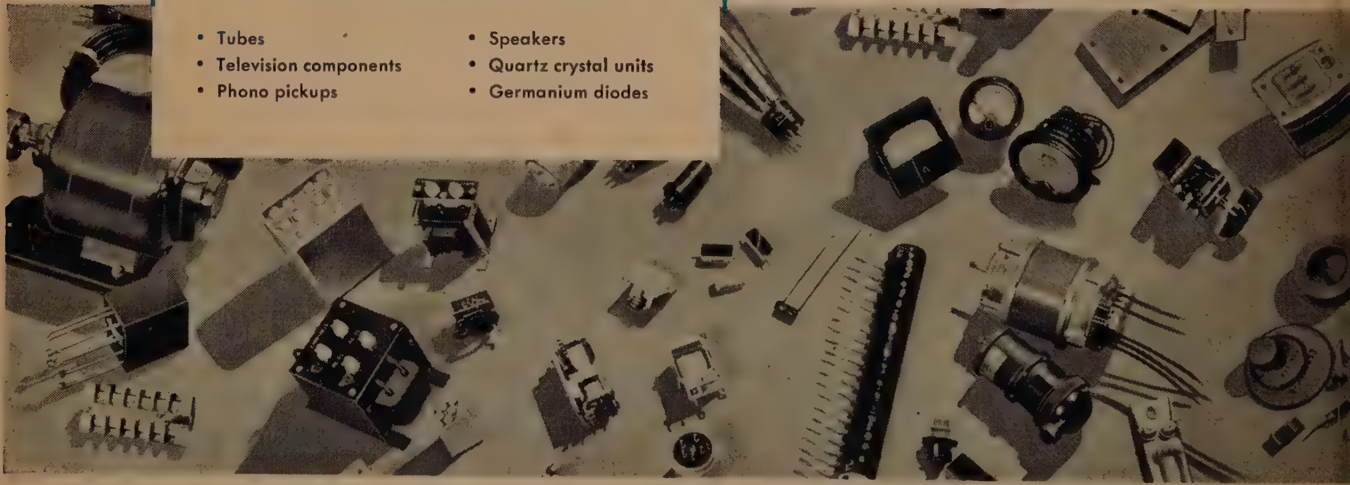

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667-8

Digest

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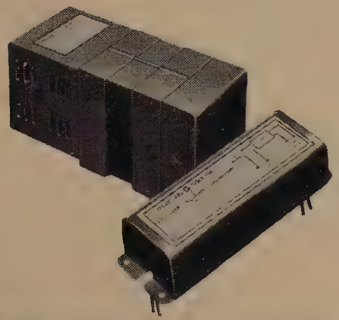

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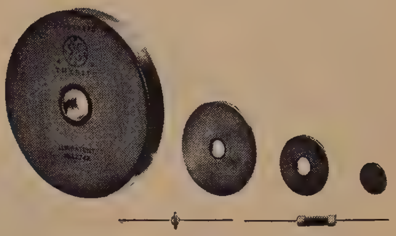

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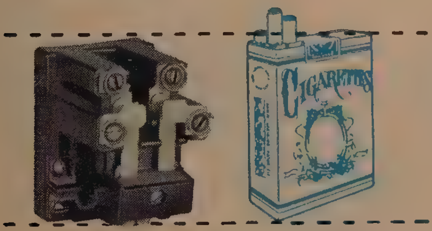

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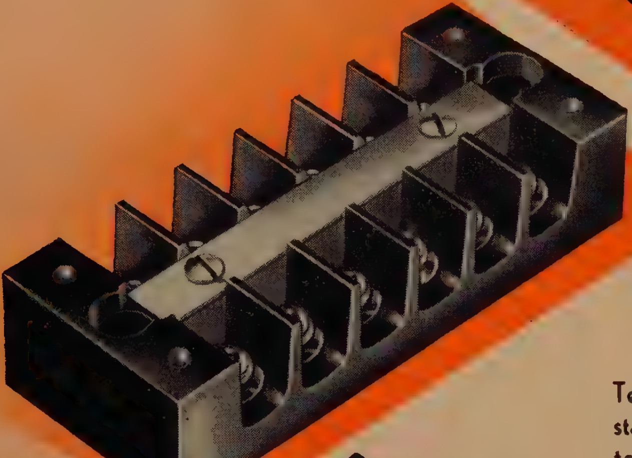

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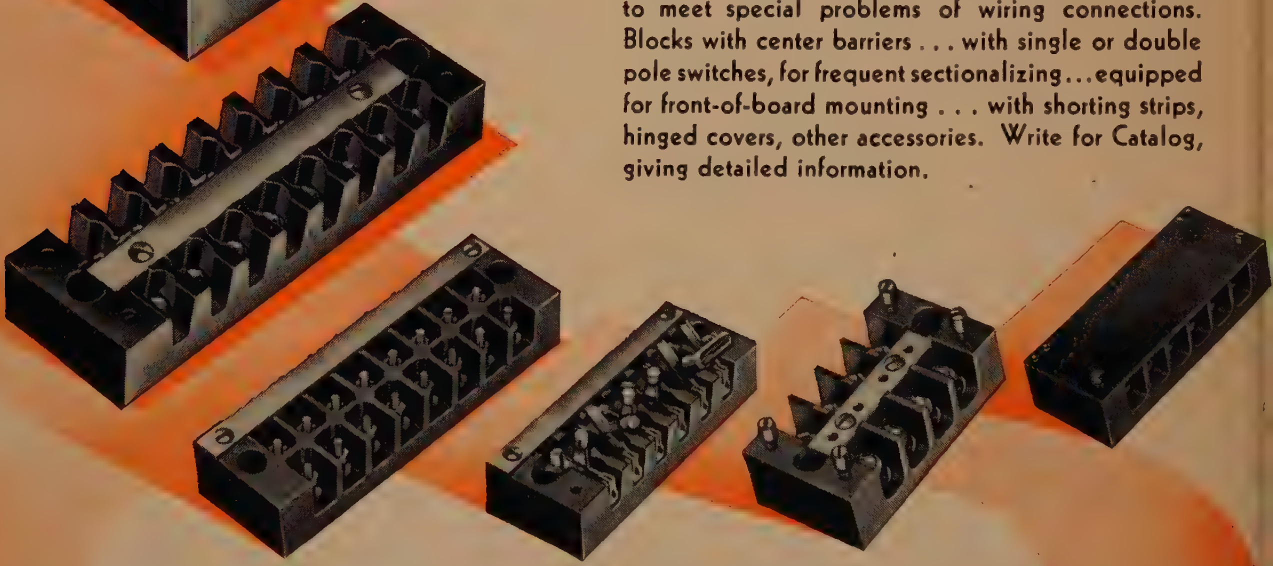

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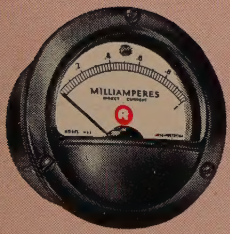

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Only one G.E.—serving industrial and domestic fields all over the globe; only one NICHROME—serving manufacturers thruout the five continents. The emblems of each, like crests of old, known and respected thruout the civilized world.

Examples of engineering and production aboard General Electric's apparatus exhibit train, the "More Power To America Special", suggest the tremendous scope of G.E. achievement—and important units such as furnace parts, thermal relays, forced-convection unit heaters, resistors and midget soldering irons testify to the significant role played by Nichrome V and Nichrome heat-and corrosion-resistant electrical alloys.

Not only Nichrome but a variety of Driver-Harris copper-nickel, nickel-iron and nickel alloys are employed extensively by G.E. in different applications.

The G.E. train is a "catalog on wheels" of apparatus products, ideas, and techniques, omitting accomplishments in the consumer field. But here too, examples could be given of Driver-Harris alloys on the job: superlative Nichrome V and Nichrome in household-appliance heating elements; D-H radio alloys—nickel-chromium, silicon-nickel, manganese-nickel, nickel-cobalt and others—in a number of electron tubes and other radio applications.

We deeply appreciate the confidence reposed in Driver-Harris products by General Electric—appreciate the responsibility such confidence imposes. It is indeed a source of great satisfaction, as we salute this symbol of G.E. achievement, the "More Power To America Special", to know that our continuing role as a supplier to G. E. is the direct result of being able to meet tough specifications that assure millions of consumers the best that money can buy.

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